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Fuels Treatment Prescriptions for Southern Utah and Northern Arizona

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COOPERATOR SYSTEMS FOR ENVIRONMENTAL MANAGEMENT
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FINAL REPORT

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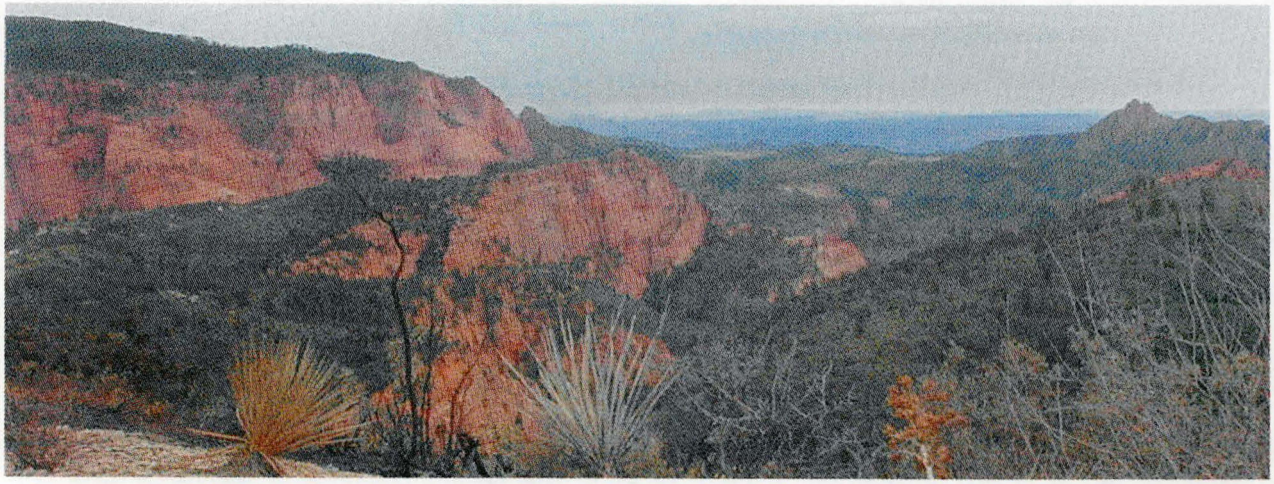
Fuels Treatment Prescriptions for Southern Utah and Northern Arizona



Submitted to:

Kevin C. Ryan, Project Leader
Fire Effects, Fire Sciences Laboratory
US Forest Service, Missoula MT
Agreement Number: 01-JV-11222048-080

By:

Rick Stratton, Fire Modeling Analyst
Systems for Environmental Management
Cooperator Agreement Number: P-233

June 13, 2003

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Deliverables

1. Cooperate with Fire Lab staff in testing spatially explicit versions of NEXUS, FARSITE, FlamMap, and FOFEM software in a Geographical Information System environment.

Status: Completed (May 2003)

Narrative: Final FARSITE modeling has been done for Ash Creek, Greenville, and Duck Creek. FlamMap modeling is completed for Ash Creek and Greenville. Spatial Nexus and FOFEM are Don Long's responsibility.

2. Cooperate with Fire Lab staff in developing and defining validity of model inputs.

Status: Completed (March 2003)

Narrative: Thirty-seven customized models have been developed for the project area, as well as two custom models (sparse grass/shrub). On-site observations and modeling runs of case study areas have been conducted to validate fuel model assignments.

3. Conduct interactive evaluations of model inputs and outputs with Southern Utah fire managers.

Status: Completed: (Feb., August, Nov. 2001 / June, Nov. 2002)

Narrative: Five meetings have been held with managers to discuss input data and modeling output. A final transfer workshop will be held in Cedar City, April 2003.

4. Use output generated from models to develop on the ground fuels treatment prescriptions.

Status: Completed: (April 2003)

Narrative: FARSITE, FlamMap, and MTT simulations have been done to assess treatment effectiveness on fire spread and behavior for Ash Creek and Greenville Bench; recommendations for prescriptions have been made. NEPA support and an anlysis of treatment effectiveness on fire growth has been conducted for the Duck Creek hazard fuels reduction project

5. Research reporting of model outputs and results.

Status: Completed: (June 2003)

Narrative: Papers for Chapters 13 (½), 15, 22, and 25 are completed and ready for submission to Joint Fire Sciences.

VEGETATION AND FUEL DATABASES

Donald Long and Rick D. Stratton

Fuel Model Development

The 65 vegetation classes were cross-walked to 44 fuel models, including barren (99) and water (98), 35 of which were "customized" models (i.e., the standardized model parameters (Anderson 1982) were altered to reflect a condition not adequately represented by the fire behavior models) and two, were custom models (i.e., 14: sparse grass-forb; 35: sparse shrub). A moderate and severe fuel model (*.FMD) was developed to adequately reflect the changes in fire growth and behavior between moderate and high/severe conditions.

The process for cross-walking vegetation classes to fuel models was as follows: First, standardized fuel model assignments (i.e., 1-13) were made in the field at plot locations by field crews and a fire modeling analyst. These preliminary crosswalks were than compared with information obtained from workshops, where local managers were shown photographs of vegetation plots and a quick fuel model assignment was made. These two sources of information were used to assign a fuel model to each vegetation class. Those fuel model assignments that were not adequately represented by the standardized models were then given a "+" or "-" (customized model). In a few cases a double "+" or "-" was assigned marking a significant change from the base model. If a condition existed, that was not characterized by a model, then a name was assigned for development of a "true" custom model (e.g., sparse grass-forb).

Once these initial assignments were made, plot data were compared with fuel model variables as a check to see that original assignments were in agreement with empirical information. Where needed minor changes were made and the custom and customized models were parameterized, where a "+" and "-" represented a 20% increase or decrease in the fuel loading and depth. Lastly, canopy characteristics (i.e., canopy cover, stand height, crown base height, crown bulk density) were developed based on field data, anecdotal observations, and previously published work.

Two sets of canopy characteristics were developed, one for FARSITE and the other for FlamMap. Canopy characteristics assignments for FARSITE included some shrub species such as pinyon-juniper (FM 19) or sagebrush (FM 33) to allow for spotting under certain conditions. No shrub canopy characteristics were applied to the FlamMap database, so that simulations would not show crown fire in shrub species.

Model Output and Testing

Table 1 (FARSITE) and Table 2 (Flammap) display the fuel model assignments by vegetation class for the moderate (FM MOD) and severe (FM SEV) conditions and associated canopy characteristics. Fire behavior output for standardized, customized, and custom models are displayed in Table 3-5. Testing and comparisons of fire behavior output with the standardized models was done using FARSITE, NEXUS, or Behave Plus. The 44 fuel models provide managers with a starting point to further customize and calibrate fire growth and behavior output to their area of interest. This can be accomplished through modifying model parameters in programs such as Behave

Plus or NEXUS, or using a conversion file (*.CNV), an adjustment factor (*.ADJ), modifying the *.FMD using the fuel model custom editor, the landscape editor, or modifying the original fuel model and canopy grids (GIS) for use in FARSITE.

Table 1. Fuel model assignments by vegetation class with FARSITE canopy characteristics.

Veg. Class	FM	FM MOD	FM SEV	CC (%)	SH (ft)	CBH (ft)	CBD (kg/m3)
1	14	99	C1	0	0	0	0
2	15	C1	1--	0	0	0	0
3	1	1↓	1	0	0	0	0
4	1	1↓	1	0	0	0	0
5	16	1--	1	0	0	0	0
6	17	1-	1	0	0	0	0
7	18	1-	1	0	0	0	0
8	18	1-	1	0	0	0	0
9	19	5	6	15	10	1	0.001
10	19	5	6	15	10	1	0.001
11	20	2-	4-	15	15	2	0.01
12	21	6-	6	15	15	2	0.02
13	22	8+	6	15	17	2	0.05
14	23	6-	4-	30	20	3	0.08
15	23	6-	4-	30	20	3	0.08
16	24	2-	4-	30	17	2	0.1
17	25	6-	4-	30	17	2	0.11
18	26	8	4	45	17	2	0.15
19	26	8	4	55	17	2	0.17
20	27	6	4	35	13	4	0.12
21	27	6	4	35	15	5	0.13
22	28	5	4-	15	10	3	0.001
23	29	6-	6+	15	18	4	0.01
24	29	6-	4-	30	20	5	0.02
25	30	2-	2	0	0	0	0
26	31	6-	6	5	3	1	0.001
27	2	2↓	2	0	0	0	0
28	32	6-	6	5	5	1	0.001
29	6	6	6	5	3	1	0.001
30	33	6-	6	1	4	1	0.001
31	34	6-	6	5	5	1	0.001
32	33	6-	6	1	4	1	0.001
33	35	99	C2	0	0	0	0
34	36	5	6	1	3	1	0.001
35	37	2-	2	0	0	0	0
36	38	5	6	5	5	1	0.001
37	39	C2	6--	0	0	0	0
38	5	5	5↑	0	0	0	0
39	40	8-	5	0	0	0	0

Veg. Class	FM	FM MOD	FM SEV	CC (%)	SH (ft)	CBH (ft)	CBD (kg/m3)
40	41	C2	6	0	0	0	0
41	41	C2	6	0	0	0	0
42	42	8+	10	60	55	4	0.02
43	43	8++	9	45	45	25	0.03
44	43	8++	9	45	60	30	0.05
45	44	8	10	80	50	30	0.08
46	44	8	10	55	60	3	0.2
47	8	8	8↑	55	70	7	0.2
48	45	8	10	50	60	4	0.15
49	45	8	10	50	45	4	0.25
50	45	8	10	50	50	6	0.25
51	9	9	9↑	40	60	10	0.1
52	9	9	9↑	40	55	10	0.1
53	9	9	9↑	40	60	10	0.18
54	46	9-	6	25	50	10	0.12
55	47	9	2-	25	60	10	0.15
56	48	9	9	25	55	7	0.12
57	49	8	10	60	65	4	0.27
58	10	10	10	55	75	5	0.3
59	10	10	10	55	60	5	0.3
60	50	8	5	25	60	4	0.27
61	35	99	C2	0	0	0	0
62	98	98	98	0	0	0	0
63	99	99	99	0	0	0	0
64	14	99	C1	0	0	0	0
65	99	99	99	0	0	0	0

FM = Fuel model
FM MOD = Fuel model moderate
FM SEV = Fuel model severe

CC = Canopy cover
SH = Stand height
CBH = Crown base height
CBD = Crown bulk density

Red = Similar vegetation types grouped into the same fuel model.

Blue = Fire behavior models (Anderson 1982).

Blue (↓ or ↑) = An adjustment factor (*.ADJ) (FARSITE) is recommended to increase or decrease the rate-of-spread.

Table 2. Fuel model assignments by vegetation class with FlamMap canopy characteristics.

Veg. Class	FM	FM MOD	FM SEV	CC (%)	SH (ft)	CBH (ft)	CBD (kg/m3)
1	14	99	C1	0	0	0	0
2	15	C1	1--	0	0	0	0
3	1	1	1	0	0	0	0
4	1	1	1	0	0	0	0
5	16	1--	1	0	0	0	0
6	17	1-	1	0	0	0	0
7	18	1-	1	0	0	0	0
8	18	1-	1	0	0	0	0
9	19	5	6	0	0	0	0
10	19	5	6	0	0	0	0
11	20	2-	4-	15	15	2	0.01
12	21	6-	6	15	15	2	0.02
13	22	8+	6	15	17	2	0.05
14	23	6-	4-	30	20	3	0.08
15	23	6-	4-	30	20	3	0.08
16	24	2-	4-	30	17	2	0.1
17	25	6-	4-	30	17	2	0.11
18	26	8	4	45	17	2	0.15
19	26	8	4	55	17	2	0.17
20	27	6	4	35	13	4	0.12
21	27	6	4	35	15	5	0.13
22	28	5	4-	15	10	3	0.001
23	29	6-	6+	15	18	4	0.01
24	29	6-	4-	30	20	5	0.02
25	30	2-	2	0	0	0	0
26	31	6-	6	0	0	0	0
27	2	2	2	0	0	0	0
28	32	6-	6	0	0	0	0
29	6	6	6	0	0	0	0
30	33	6-	6	0	0	0	0
31	34	6-	6	0	0	0	0
32	33	6-	6	0	0	0	0
33	35	99	C2	0	0	0	0
34	36	5	6	0	0	0	0
35	37	2-	2	0	0	0	0
36	38	5	6	0	0	0	0
37	39	C2	6--	0	0	0	0
38	5	5	5	0	0	0	0
39	40	8-	5	0	0	0	0

Veg. Class	FM	FM MOD	FM SEV	CC (%)	SH (ft)	CBH (ft)	CBD (kg/m3)
40	41	C2	6	0	0	0	0
41	41	C2	6	0	0	0	0
42	42	8+	10	60	55	4	0.02
43	43	8++	9	45	45	25	0.03
44	43	8++	9	45	60	30	0.05
45	44	8	10	80	50	30	0.08
46	44	8	10	55	60	3	0.2
47	8	8	8	55	70	7	0.2
48	45	8	10	50	60	4	0.15
49	45	8	10	50	45	4	0.25
50	45	8	10	50	50	6	0.25
51	9	9	9	40	60	10	0.1
52	9	9	9	40	55	10	0.1
53	9	9	9	40	60	10	0.18
54	46	9-	6	25	50	10	0.12
55	47	9	2-	25	60	10	0.15
56	48	9	9	25	55	7	0.12
57	49	8	10	60	65	4	0.27
58	10	10	10	55	75	5	0.3
59	10	10	10	55	60	5	0.3
60	50	8	5	25	60	4	0.27
61	35	99	C2	0	0	0	0
62	98	98	98	0	0	0	0
63	99	99	99	0	0	0	0
64	14	99	C1	0	0	0	0
65	99	99	99	0	0	0	0

FM = Fuel model
FM MOD = Fuel model moderate
FM SEV = Fuel model severe

CC = Canopy cover
SH = Stand height
CBH = Crown base height
CBD = Crown bulk density

Red = Similar vegetation types grouped into the same fuel model.

Blue = Fire behavior models (Anderson 1982).

Table 3. Fire behavior output by vegetation class for standardized, customized, and custom models, for both moderate and severe conditions.

Veg. Class	FM	FM MOD	ROS (ft/min)	FL (ft)	FM SEV	ROS (ft/min)	FL (ft)
1	14	99	0	0	C1	26.8	1.7
2	15	C1	16.5	1.3	1--	95.2	3.6
3	1	1	202.7	6.3	1	257.7	7.4
4	1	1	202.7	6.3	1	257.7	7.4
5	16	1--	62.3	2.9	1	257.6	7.4
6	17	1-	149.6	4.9	1	257.6	7.4
7	18	1-	149.6	4.9	1	257.6	7.4
8	18	1-	149.6	4.9	1	257.6	7.4
9	19	5	21.9	4.4	6	77.4	9.3
10	19	5	21.9	4.4	6	77.4	9.3
11	20	2-	52.4	6.5	4-	158.4	25.7
12	21	6-	45.9	6.1	6	77.4	9.3
13	22	8+	4.2	1.6	6	77.4	9.3
14	23	6-	45.9	6.1	4-	158.4	25.7
15	23	6-	45.9	6.1	4-	158.4	25.7
16	24	2-	52.4	6.5	4-	158.4	25.7
17	25	6-	45.9	6.1	4-	158.4	25.7
18	26	8	3.5	1.4	4	198	31.5
19	26	8	3.5	1.4	4	198	31.5
20	27	6	57.4	7.5	4	198	31.5
21	27	6	57.4	7.5	4	198	31.5
22	28	5	21.9	4.4	4-	158.4	25.7
23	29	6-	45.9	6.1	6+	92.9	11.1
24	29	6-	45.9	6.1	6+	92.9	11.1
25	30	2-	52.4	6.5	2	95.9	10.2
26	31	6-	45.9	6.1	6	77.4	9.3
27	2	2	65.6	7.9	2	95.9	10.2
28	32	6-	45.9	6.1	6	77.4	9.3
29	6	6	57.4	7.5	6	77.4	9.3
30	33	6-	45.9	6.1	6	77.4	9.3
31	34	6-	45.9	6.1	6	77.4	9.3
32	33	6-	45.9	6.1	6	77.4	9.3
33	35	99	0	0	C2	24.3	4.1
34	36	5	21.9	4.4	6	77.4	9.3
35	37	2-	52.4	6.5	2	95.9	10.2
36	38	5	21.9	4.4	6	77.4	9.3
37	39	C2	8.5	1.9	6--	46.5	5.8
38	5	5	21.9	4.4	5	64.1	9.8
39	40	8-	2.8	1.1	5	64.1	9.8

Veg. Class	FM	FM MOD	ROS (ft/min)	FL (ft)	FM SEV	ROS (ft/min)	FL (ft)
40	41	C2	8.5	1.9	6	77.4	9.3
41	41	C2	8.5	1.9	6	77.4	9.3
42	42	8+	4.2	1.6	10	21.6	8.2
43	43	8++	4.9	1.9	9	22.4	4.7
44	43	8++	4.9	1.9	9	22.4	4.7
45	44	8	3.5	1.4	10	21.6	8.2
46	44	8	3.5	1.4	10	21.6	8.2
47	8	8	3.5	1.4	8	4.7	1.7
48	45	8	3.5	1.4	10	21.6	8.2
49	45	8	3.5	1.4	10	21.6	8.2
50	45	8	3.5	1.4	10	21.6	8.2
51	9	9	16.5	3.8	9↑	22.4	4.7
52	9	9	16.5	3.8	9↑	22.4	4.7
53	9	9	16.5	3.8	9↑	22.4	4.7
54	46	9-	13.2	3.1	6	77.4	9.3
55	47	9	16.5	3.8	2-	75.5	8.2
56	48	9	16.5	3.8	9	22.4	4.7
57	49	8	3.5	1.4	10	21.6	8.2
58	10	10	12.9	5.9	10	21.6	8.2
59	10	10	12.9	5.9	10	21.6	8.2
60	50	8	3.5	1.4	5	64.1	9.8
61	35	99	0	0	C2	24.3	4.1
62	98	98	0	0	98	0	0
63	99	99	0	0	99	0	0
64	14	99	0	0	C1	26.8	1.7
65	99	99	0	0	99	0	0

FM = Fuel model
FM MOD = Fuel model moderate
FM SEV = Fuel model severe
ROS = Rate-of-spread (ft/min)
FL = Surface flame length (ft)
Red = Similar vegetation types grouped into the *same* fuel model
Blue = Fire behavior models (Anderson 1982)

Model Inputs:
Slope = 0%
Midflame Windspeed = 7 mph
Fuel Moisture (MOD) = 6% (1-hr), 7% (10-hr), 8% (100-hr), 120% (live)
Fuel Moisture (SEV) = 3% (1-hr), 4% (10-hr), 5% (100-hr), 70% (live)

Table 4. Moderate fire behavior output by fuel model in increasing order.

FM	ROS (ft/min)
14	0
35	0
98	0
14	0
99	0
40	2.8
26	3.5
44	3.5
8	3.5
45	3.5
49	3.5
50	3.5
22	4.2
42	4.2
43	4.9
39	8.5
41	8.5
10	12.9
46	13.2
15	16.5
9	16.5
47	16.5
48	16.5
19	21.9
28	21.9
36	21.9
38	21.9
5	21.9
21	45.9
23	45.9
25	45.9
29	45.9
31	45.9
32	45.9
33	45.9
34	45.9
20	52.4
24	52.4
30	52.4
37	52.4
27	57.4
6	57.4
16	62.3

FM	FL (ft)
14	0
35	0
98	0
14	0
99	0
40	1.1
26	1.3
44	1.4
8	1.4
45	1.4
49	1.4
50	1.4
22	1.4
42	1.6
43	1.6
39	1.9
41	1.9
10	1.9
46	2.9
15	3.1
9	3.8
47	3.8
48	3.8
19	4.4
28	4.4
36	4.4
38	4.4
5	4.4
21	4.9
23	4.9
25	5.9
29	6.1
31	6.1
32	6.1
33	6.1
34	6.1
20	6.1
24	6.1
30	6.1
37	6.3
27	6.5
6	6.5
16	6.5

FM	ROS (ft/min)
2	65.6
17	149.6
18	149.6
1	202.7

FM	FL (ft)
2	6.5
17	7.5
18	7.5
1	7.9

FM = Fuel model (moderate)
ROS = Rate-of-spread (ft/min)
FL = Surface flame length (ft)
Fuel Moisture = 6% (1-hr), 7% (10-hr), 8% (100-hr), 120% (live)

Table 5. Severe fire behavior output by fuel model in increasing order.

FM	ROS (ft/min)
98	0
99	0
8	4.7
44	21.6
45	21.6
49	21.6
42	21.6
10	21.6
43	22.4
9	22.4
48	22.4
35	24.3
14	26.8
14	26.8
39	46.5
40	64.1
50	64.1
5	64.1
47	75.5
22	77.4
41	77.4
46	77.4
19	77.4
36	77.4
38	77.4
21	77.4
31	77.4
32	77.4
33	77.4
34	77.4
6	77.4
29	92.9

FM	FL (ft)
98	0
99	0
8	1.7
14	1.7
14	1.7
15	3.6
35	4.1
43	4.7
9	4.7
48	4.7
39	5.8
16	7.4
17	7.4
18	7.4
1	7.4
44	8.2
45	8.2
49	8.2
42	8.2
10	8.2
47	8.2
22	9.3
41	9.3
46	9.3
19	9.3
36	9.3
38	9.3
21	9.3
31	9.3
32	9.3
33	9.3
34	9.3

FM	ROS (ft/min)
15	95.2
30	95.9
37	95.9
2	95.9
28	158.4
23	158.4
25	158.4
20	158.4
24	158.4
26	198
27	198
16	257.6
17	257.6
18	257.6
1	257.7

FM	FL (ft)
6	9.3
40	9.8
50	9.8
5	9.8
30	10.2
37	10.2
2	10.2
29	11.1
28	25.7
23	25.7
25	25.7
20	25.7
24	25.7
26	31.5
27	31.5

FM = Fuel model (severe)
ROS = Rate-of-spread (ft/min)
FL = Surface flame length (ft)
Fuel Moisture = 3% (1-hr), 4% (10-hr), 5% (100-hr), 70% (live)

References

Anderson, H. E. 1982. **Aids to determining fuel models for estimating fire behavior**. Gen. Tech. Rep. INT-122. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 22 p.

FARSITE and FLAMMAP

Rick D. Stratton

FARSITE

FARSITE (**F**ire **Ar**ea **Si**mula**t**or) is a two-dimensional deterministic model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain, fuels, and weather (Finney 1998). To do this, FARSITE incorporates existing fire behavior models of surface fire spread (Rothermel 1972; Albini 1976), crown fire spread (Rothermel 1991; Van Wagner 1977, 1993), spotting (Albini 1979), point-source fire acceleration (Forestry Canada Fire Danger Group 1992), and fuel moisture (Nelson 2000) with GIS data. Simulation output is in tabular, vector, and raster formats.

FARSITE was initially developed for management support of prescribed natural fires (PNFs), now called fire use (Finney 1993). Subsequently, FARSITE been extended to model wildfires (Finney and Andrews 1994), assessing the effectiveness and economics of fuel treatments (Stratton 2003; Stephens 1998; Finney *et al* 1997; Van Wagtendonk 1996) and fire management planning.

FARSITE terrain data (i.e., elevation, slope, aspect) was obtained and/or derived from a 30-meter Digital Elevation Model (DEM). Canopy characteristics (i.e., canopy cover, stand height, crown base height, crown bulk density) were developed based on field data, anecdotal observations, and previously published work, and are displayed in Chapter 13, Table 1. Duff and coarse woody information, for modeling post-frontal combustion, w*as not* developed for the project area. For a case study application of the FARSITE model refer to Chapter 22 (Ash Creek). The FARSITE model and technical documentation is available at: http://www.fire.org/.

FlamMap

FlamMap (Finney, in preparation) is a spatial fire behavior mapping and analysis program, which requires a FARSITE landscape file (*.LCP), as well as terrain, fuel, and weather data. However, unlike FARSITE, FlamMap assumes that *every* pixel on the raster landscape burns and makes fire behavior calculations (e.g., fireline intensity, flame length) for each location (i.e., cell), *independent* of one another. That is, there is no predictor of fire movement across the landscape and weather and wind information can be held constant. By so doing, FlamMap output lends itself well to landscape comparisons (e.g., pre- and post-treatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessments (Stratton 2003; Finney 2000). For a case study application of the FlamMap model refer to Chapter 22 (Ash Creek) and Chapter 25 (Greenville Bench). The FlamMap model is available at: http://www.fire.org/.

Weather Data

Historical weather information for use in FARSITE and FlamMap were obtained from Remote Automated Weather Stations (RAWS). FARSITE weather inputs included maximum and minimum temperature and relative humidity, precipitation, and hourly wind and weather. FlamMap inputs were derived from RAWS weather imported into

Fire Family Plus (Cohen and others 1994; Main and others 1990) to compute historical wind speeds and direction.

Model Calibration

To produce fire growth and behavior output consistent with observations, model checking, comparisons, and modifications are done (i.e., calibration) with known fire perimeters and weather conditions (Finney 2000). Calibration can also be accompanied by simulation modeling in areas of interest (i.e., case study areas) and comparing model output with empirical data and personal observations.

Wildland Fires

Three fires were used to calibrate the model output the Sanford Fire (April-June 2002; 78,000 ac), the Langston Fire Use (August 2001; 600 ac), and the Price Canyon Fire (July 2002; 2,900 ac). The Sanford Fire (Panguitch, UT) was useful in modeling low to extreme environmental conditions, with considerable elevation, topographic, and vegetative change. Most fuel models (FM) (Anderson 1982) were represented in the fire area, and canopy characteristics and their influence on crown fire transitions, spotting, and spread were analyzed. Figure 1 displays calibration of the model to the NE head of the fire during a strong frontal passage, June 7-9 (16,286 acres). The northeast head of the June 2nd progression was used as an ignition line.

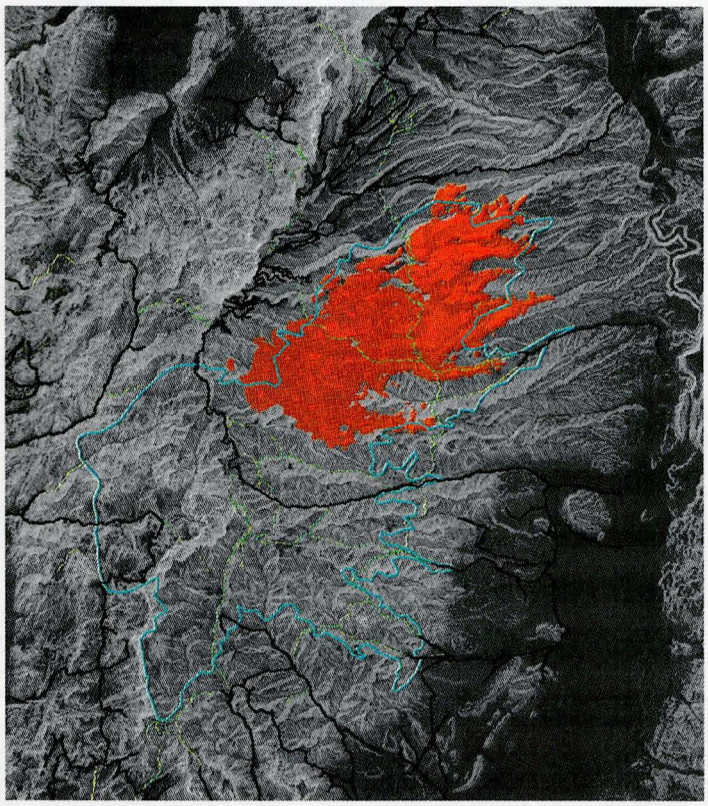

Figure 1. Output from the calibration of the FARSITE model (red) to the northeast head of the Sandford Fire (Panguitch, UT) during a frontal passage, June 7-9, 2002 (16,286 acres). The base layer is slope overlaid with roads (black), trails (green), and the fire perimeter on the 10th of June (light blue).

The Langston Fire Use (Zion National Park, UT) allowed testing of flanking and backing surface spread rates under moderate weather conditions. Vegetation types consisted of Douglas fir and ponderosa pine in the drainages (FM 8), manzanita (FM 5), oak brush (FM 5, 6), and ponderosa pine (FM 9) on the plateaus, and barren areas associated with steep, rocky faces (FM 99).

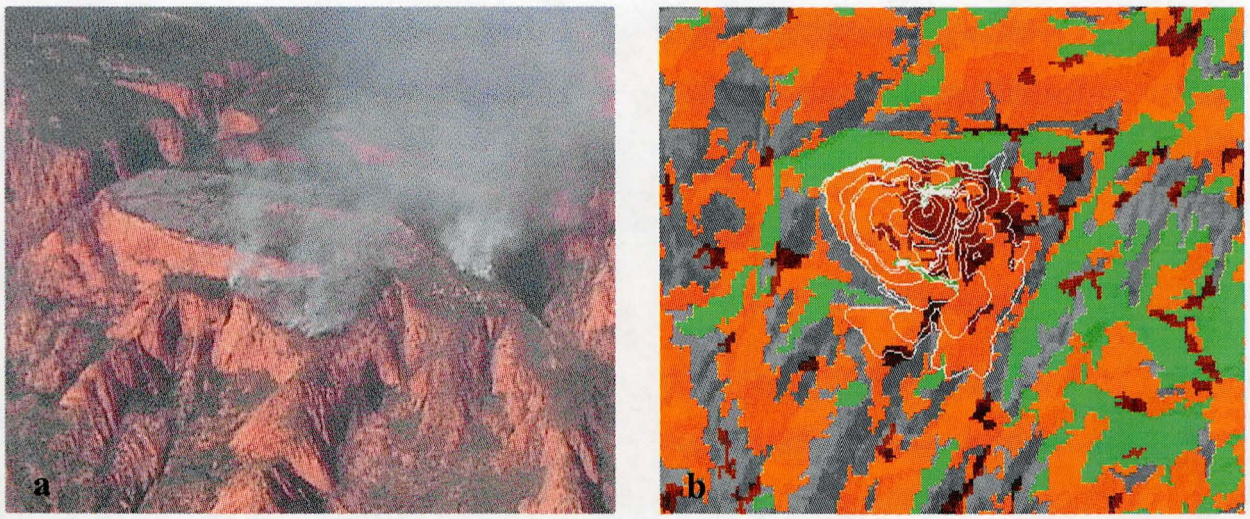

Figure 2. (a) Photograph looking northeast of the Langston Fire Use, Zion National Park, UT (August 2001; 600 ac) and (b) 1-hr progressions of a FARSITE simulation (white) overlaid by fuel models. Fuel models 8 and 9 are denoted as green and dark brown areas, shrubs are orange, and barren is gray.

The Price Canyon Fire occurred 14 miles northwest of Price, UT, just outside the project area. Based on the Demonstration project's methodology and field data, FARSITE terrain and vegetation grids were developed to assist with the Price Canyon Fire Entrapment Investigation Report (USDI and USDA 2002). Simulations were done to construct a fire chronology and aid fire behavior analysts in there investigation (Figure 3). Known fire perimeters and behavior were compared with predicted results to calibrate vegetation and fuel parameters.

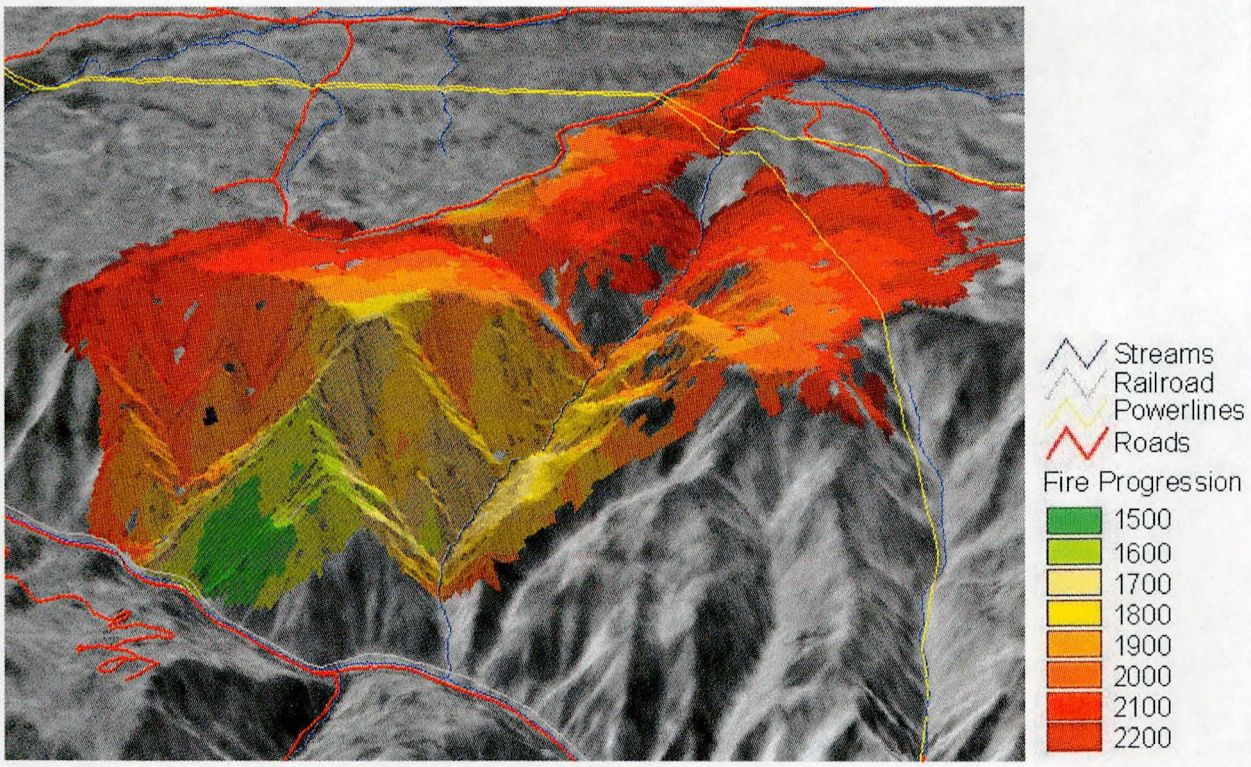

Figure 3. FARSITE simulation of the Price Canyon Fire, Helper, UT (July 2002; 2,900 ac) looking east.

Case Studies

Frequent modeling in case study areas also provided for model checking and adjusting. The Ash Creek and Greenville Bench project areas allowed testing in grasslands, sage-grass, sagebrush, mixed shrub, and pinyon-juniper types—representing approximately 60% of the entire 15-million acre project area. Analysis in the Duck Creek area provided for checking in higher elevation species, such as aspen, spruce, and fir.

Model Findings

Surface Fire

Surface spread rates were one of the most accurately predicted fire characteristics. Growth patterns matched surprisingly well with recent fires, although over-prediction of surface spread still occurs (Rothermel 1972). Under severe fuel and temperature conditions, the severe custom fuel model (severe.FMD) may over-predict without the influence of strong winds. During these conditions, an adjustment factor (*.ADJ) is recommended in fuel models 38, 47, and 51-53 to increase the rate of spread. Under moderate conditions an adjustment factor for fuel models 3, 4, and 27 may be needed to decrease the spread rate. Under most but the extreme conditions, the moderate custom fuel model (mod.FMD) should be sufficient.

Spotting

Spotting in FARSITE is stochastic (Finney 1998) and the numbers of embers lofted and burning when they reach the ground, ahead of the fire front, are dependent on the spotting model (Albini 1979) and largely influenced by the ignition frequency and canopy characteristics. To adequately model fire growth and spotting in shrub species, some vegetation types were given canopy characteristics. As a general rule, an ignition frequency of .10% in the moderate custom fuel model and .05% in the severe fuel model is sufficient to model spot fire growth. The key is to get a adequate amount of spot fires to be representative of observed conditions, yet few enough to allow the system to complete the simulation in a timely manner.

Crown Fire Activity

Crown fire activity is a very useful FARSITE output, particularly in assessing the effectiveness of landscape modifications on fire behavior. Crown fire occurrence and spotting in fuel model 8 and its derivatives, is very rare, and a transition to "10's" (e.g., severe.FMD) is needed to model torching and active crowning. Shrub dominated areas (e.g., pinyon-juniper) tend to underpredicted active crown fire, whereas *some* conifer areas seemed to predict active crown fire fairly well during severe burning conditions. However, as a general rule FARSITE will underpredict active crown fire (Cruz and others 2003; Fulé and others 2001; Scott and Reinhardt 2001).

Various shrublands have been assigned canopy characteristics, so passive crown fire in these areas is likely to occur during high and severe burning conditions. Although technically these are not true crown fires, the shrubs contain containing crown characteristics and are modeled as "small trees," hence torching and crown fire runs will occur.

Flame Length

A limitation to flame length output in FARSITE is the prediction of only surface flame lengths (Finney 1998; Byram 1959). Therefore, flame length output in grass and shrublands are reasonable, but flame lengths in tree species are inadequate (Rothermel 1991). One way to increase flame lengths to be more representative in taller shrub species (e.g., pinyon-juniper) is to output fire intensity and then use it in Thomas' equation ($L=0.45I^{0.46}$; where "L" is flame length and "I" is intensity) to predict surface flame lengths (Thomas 1963; Rothermel 1991).

Fire Intensity

Surface fire estimates in FARSITE are satisfactory in estimating fireline intensity and heat per unit area. However, crown fire intensity—at times—may be underestimated as well as biased to lower values.

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ASH CREEK CASE STUDY ANALYSIS

Rick D. Stratton, Maureen Mislivets, and Donald Long

Abstract

This paper presents a methodology for assessing the effectiveness of landscape fuel treatments on fire growth and behavior. Treatment areas were selected by fire managers from the Bureau of Land Management (BLM) based on the threat of fire to communities and the need for range and wildlife improvement. A fire density grid was derived from the BLM's fire start layer to identify historically high ignition areas. Fire Family Plus was used to summarize and analyze historical weather and calculate seasonal severity and percentile reports. Information from Fire Family was used in FARSITE and FlamMap to model pre- and post-treatment effects on fire growth, spotting, fireline intensity, surface flame length, and the occurrence of crown fire. This procedure provides managers with a quantitative measure of treatment effectiveness as well as spatial output that can be used for analyzing fuel treatment effectiveness, burn plan development, NEPA documentation, public education, etc.

Introduction

Fuel modifications are receiving renewed interest as protection strategies, particularly in wildland-urban areas (Agee and others 2000). This is a result of costly fire seasons like 2000 and 2002, new national directives with increased funding (USDA Forest Service and USDI 2000), a recognition of a change in fuel composition, structure, and loading, and fire manager's desire, yet limited ability, to control large fires. The primary purpose of a fuel treatment is to change the behavior of a fire entering a fuel-altered zone, thus lessening the impact of that fire to an area of concern. This is best achieved by fragmenting the fuel complex and repeatedly disrupting or locally blocking fire growth, thus increasing the likelihood that suppression will be effective or weather conditions will change (Finney 2000).

Recent research suggests that landscape-scale fuel modifications, such as prescribed fire, are the most effective way to modify the behavior and growth of large fires (Finney 2001). However, the effectiveness of fuel treatments remain a subject of debate due in part to the weather conditions they will or will not perform under, treatment method, completeness of the application, treatment design (i.e., placement, pattern, size), and the difficultly in evaluating the effectiveness of the proposed treatment. Simulation modeling allows the user to partially address these issues under various weather and fuel scenarios and provides a "tested" outcome for field application.

This paper presents a methodology for assessing the effectiveness of landscape fuel treatments on fire growth and behavior by utilizing previous fire locations, historical weather, and fire growth and behavior models.

Analysis Area

Ash Creek is located approximately 20 miles south of Cedar City, Utah and is adjacent to the communities of New Harmony and Harmony Heights (Figure 1). The project area (approx. 2,000 acres; 5,300 ft) is on Bureau of Land Management (BLM) administered land and bounded tightly by private ownership to the north, Interstate 15 (I-15) to the east, the Dixie National Forest and Pine Valley Mountain Wilderness Area to the west,

and BLM, State, and private inholdings to the south. The area has seen an increase in urban development due to its rural setting and views of the Kolob Fingers (Zion National Park), inviting climate, and close proximity to various recreational sites and metropolitan areas.

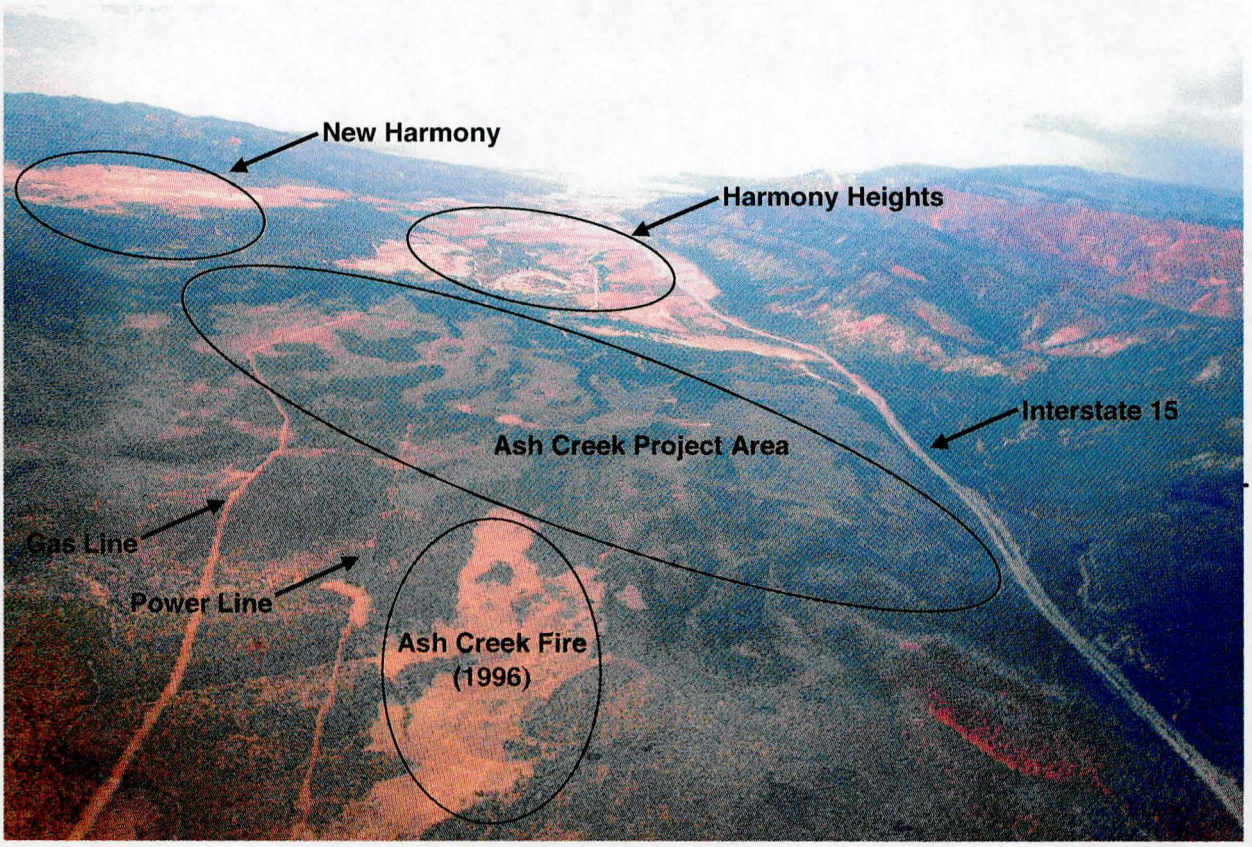

Figure 1. Aerial view of the Ash Creek project area looking northeast. Photo by Paul Briggs.

Located on a relatively flat, east, southeast bench, understory vegetation is primarily crested wheatgrass (*Agropyron cristatum*), bluebunch wheatgrass (*Elymus spicatus*), junegrass (*Koeleria macrantha*) (1-2 ft), sage brush (*Artemisia tridentata*) (1-3 ft), oak (*Quercus turbinella*; *Quercus gambelii*) in some draws (4-15 ft), and smaller amounts of Utah serviceberry (*Amelanchier alnifolia*), bitterbrush (*Purshia tridentata*), and true mountain mahogany (*Cercocarpus montanus*) (2-15 ft). Utah juniper (*Juniperus osteosperma*) and scattered pinyon pine (*Pinus edulis*), in varying density, is the dominate overstory species (10-35 ft).

Summer cold fronts contribute to strong winds that are channeled through the I-15-Black Ridge corridor and into the project area. The effect of these winds on fire shape are evidenced in the Ash Creek Fire of 1996 (~500 acres) (Figure 1). The area has a

history of fires attributed to recreational use, I-15 through traffic, and lightning on Black Ridge (6,400 ft) to the east and the Pine Valley Mountains to the west (10,000 ft).

The objectives of the project are to reduce fire intensity, occurrence of crown fire, and mid-/long-range spotting and to increase native plant diversity and enhance wildlife forage. This was accomplished through herbicide application and fuel reduction. Treatment boundaries were delineated by ownership, previously chained areas (1960's), and wildlife requirements and is reflected in an asymmetrical, amoeboid design. Sage-dominated areas were applied with several applications of a herbicide (Tebuthiuron or "Spike"). Encroaching juniper was manually cut (lop-and-scatter) and is being followed up with pile and broadcast burning.

Methods

Specific information about the project area, such as objectives of the proposed treatment (e.g., wildfire control, wildlife enhancement), type of treatment (e.g., prescribed fire, manual thinning), pre- and post-treatment condition of the entire fuel complex, and supporting Geographic Information System (GIS) data were obtained from the BLM. A thirty-two year fire ignition layer for the BLM and Forest Service was used to derive a fire density GRID, using ArcView/Spatial Analyst (ESRI 2000) [When local fire data is unavailable, this information can be retrieved for Forest Service units from the National Interagency Fire Management Integrated Database (NIFMID) (USDA Forest Service 1993), using the Kansas City Fire Access Software (KCFAST) (USDA Forest Service 1996), fire occurrence information retrieval site; fire information for the Department of Interior is available on a yearly basis via a CD-ROM (USDI Park Service 2001)].

The locations of the nearest Remote Automated Weather Stations (RAWS) were identified and reporting history and site characteristics were analyzed to determine the most adequate station for the project area. Due to the channeling effect of the winds through the project area, one station was used to obtain wind speed and direction (White Reef; 16 yr history), and another was used to for the weather (Enterprise; 29 yrs). Historical weather information was downloaded from NIFMID/KCFAST, fire occurrence information retrieval site and imported into Fire Family Plus (Bradshaw and McCormick 2000).

Fire Family Plus

Fire Family Plus is a fire climatology and occurrence program that combines and replaces the PCFIRDAT (Cohen and others 1994; Main and others 1990), PCSEASON (Cohen and others 1994; Main and others 1990), FIRES (Andrews and Bradshaw 1997), and CLIMATOLOGY (Bradshaw and Fischer 1984) programs into a single package with a graphical user interface. It allows the user to summarize and analyzing weather observations and compute fire danger indexes based on the National Fire Danger Rating System (NFDRS) (Bradshaw and others 1983; Burgan 1988).

Fuel moistures (i.e., 1-, 10-, 100-hr, live herbaceous, live woody) were obtained from a Fire Family *Percentile Weather Report*. Calculated fuel moistures were compared with local field sampling to validate and adjust the values. Wind speed, temperature, and relative humidity were obtained from a *Seasonal Severity Report*; wind direction was

obtained from a *Wind Speed vs. Direction Report*. Wind speeds were modified to account for persistent gusts (NOAA 2003) and directions were developed based on actual hourly RAWS data that adequately represented the appropriate percentile weather.

All weather and fuel moisture information was recorded at the 75th (moderate), 85th (high), and 95th (very high) percentile (Table 1). In other words, weather occurring during the reporting period (June 1-September 30) 25% of the time is represented by the 75th percentile, 15% of the time for the 85th percentile, and so forth. All climatological and fuel variables were then used to develop the required weather and wind files/inputs for FARSITE and FlamMap.

Table 1. Weather and fuel moisture information for the 75th, 85th, and 95th percentile as reported by Fire Family Plus and modified as noted (*/**).

	75th	85th	95th
1-hr (%)	4	4	3
10-hr (%)	6	5	5
100-hr (%)	9	7	6
Live Herbacious (%)*	90	80	60
Live Woody (%)*	110	100	90
Temp. Min. (°F)	56	59	64
Temp. Max. (°F)	87	89	92
RH Min. (°F)	16	14	10
RH Max. (°F)	47	40	28
20-ft Windspeed (mph)**	17	19	23
Wind Direction (°)***	190-235	190-235	190-235

*Adjusted from the *Seasonal Severity Report* based on local field sampling.

**Adjusted from the *Seasonal Severity Report* to account for wind gusts (NOAA 2003).

***During the burn period (1100-1900 hrs).

FARSITE

FARSITE (**Fi**re **Ar**ea **Si**mulator) is a two-dimensional deterministic model for spatially and temporally simulating the spread and behavior of fires under conditions of heterogeneous terrain (i.e., elevation, slope, aspect), fuels, and weather (Finney 1998). To do this, FARSITE incorporates existing fire behavior models of surface fire spread (Roth 1972; Albini 1976), crown fire spread (Van Wagner 1977, 1993), spotting (Albini 1979), point-source fire acceleration (Forestry Canada Fire Danger Group 1992), and

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FlamMap (Finney, in preparation) is a spatial fire behavior mapping and analysis program, which requires a FARSITE landscape file (*.LCP), as well as terrain, fuel, and weather data. However, unlike FARSITE, FlamMap assumes that *every* pixel on the raster landscape burns and makes fire behavior calculations (e.g., fireline intensity, flame length) for each location (i.e., cell), *independent* of one another. That is, there is no predictor of fire movement across the landscape and weather and wind information can be held constant. By so doing, FlamMap output lends itself well to landscape comparisons (e.g., pre- and post-treatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessments.

Vegetation and Fuel Models

Spatial vegetation data for the project area was extracted from a larger 15 million acre study area (Long and others, in preparation). A supervised classification of LANDSAT Thematic Mapper data—path 33 and rows 37 and 38—was used with ERDAS IMAGINE software (ERDAS 1999), incorporating polygons created by the IPW image processing program (Frew 1990). A maximum likelihood algorithm in ERDAS was used to classify the imagery based on a statistical representation of spectral signatures for each vegetation class created from field sampling. Ancillary layers, including land use and land cover, were used in combination with the classified imagery to assign polygons to one of 65 final vegetation classes.

The vegetation classes were cross-walked to 44 fuel models (including barren and water), 35 of which were "customized" models (i.e., the standardized model parameters (Anderson 1982) were altered to reflect a condition not adequately represented by the fire behavior models) and two, were custom models (i.e., 14: sparse grass-forb; 35: sparse shrub). Canopy cover, stand height, crown-base height, and crown bulk density were developed based on field data, anecdotal observations, and published work. Moderate and severe custom fuel files (*.FMD) were built to reflect the differences in fire behavior between moderate and high/severe conditions.

Terrain, fuel model, and canopy information was used to construct two modeling landscapes: pre-treatment and post-treatment. Sage-dominated areas were assigned either a fire behavior model (2, 6) or a customized model (e.g., 2-, 5+, 6-, etc; where the "-" or "+" represents a 20% change in the loading and depth). To simulate the effect of the Tebuthiuron, treated areas were reassigned a fuel model representing a 10-30% reduction in the shrub component. In some areas an adjustment factor (*.ADJ) was used to change the rate-of-spread without affecting other fire behavior outputs.

Pre-treatment stands of pinyon-juniper were assigned a standardized fuel model (4, 6) or a customized model (4-, 6-, 6--), *each with varying canopy characteristics*. Lop-and-scattered pinyon-juniper that was later pile and/or broadcast burned was reassigned a fire behavior fuel model (2, 5, 6, 11, 12), a customized model (4-, 5+, 6-, 6--), or a custom model (i.e., 14, 35); in general stand height, canopy cover, crown bulk density, and crown base height was eliminated, or reduced substantially.

Calibration

To produce fire growth and behavior output consistent with observations, model checking, modifications, and comparisons were done (i.e., calibration) with known fire perimeters and weather conditions (Finney 2000). Two fires were used to calibrate the model output, the Sanford Fire (April-June 2002; 78,000 ac) and the Langston Fire Use (August 2001; 600 ac). The Sanford Fire (Panguitch, UT) was useful in modeling low to extreme climatic conditions, with substantial elevational, topographic, and vegetative variation. Most fuel models were represented in the fire area, and canopy characteristics and their influence on crown fire transitions, spotting, and spread were analyzed. The Langston Fire Use (Zion National Park, UT) allowed testing of flanking and backing surface rates-of-spread in moderate weather conditions, on relatively flat terrain, and in fuel models 5, 8, 9, and 10.

Modeling Fire Growth and Spotting: FARSITE

To model fire growth and spotting potential, a single-source ignition in FARSITE was started in a historically high ignition area, as identified by the fire density grid. I-15 was imported as a barrier to surface spread, but was not impermeable to spotting. All fire simulations were modeled *without* suppression. One-day simulations, with a burn period of 1100 to 1900 hours, were run representing the 75th, 85th, and 95th, percentile weather and fuel conditions. The simulation process was repeated multiple times—with the same ignition point, as well as in other high ignition areas—to sample the variation in predicted fire size, shape, common spread pathways, spotting frequency and distance, etc. Based on these multiple runs, two of the "most representative" simulations were selected for each percentile level (6 in all).

Calculating Fireline Intensity, Flame Length, and Crown Fire Activity: FlamMap

To calculate pre- and post-treatment fireline intensity, surface flame length, and crown fire activity, FARSITE terrain, fuel, and weather information was imported into FlamMap. Weather and fuel moisture conditions representing the 75th, 85th, and 95th percentile were used to generate the fire behavior data (18 output grids).

Results

Figure 2 are pre- and post-treatment FARSITE simulations for the 85th percentile draped over a 3-D landscape. Each color represents a 1-hour time-step or progression of the fire. Table 2 summarizes fire size and spotting for each of the three percentiles, pre- and post-treatment.

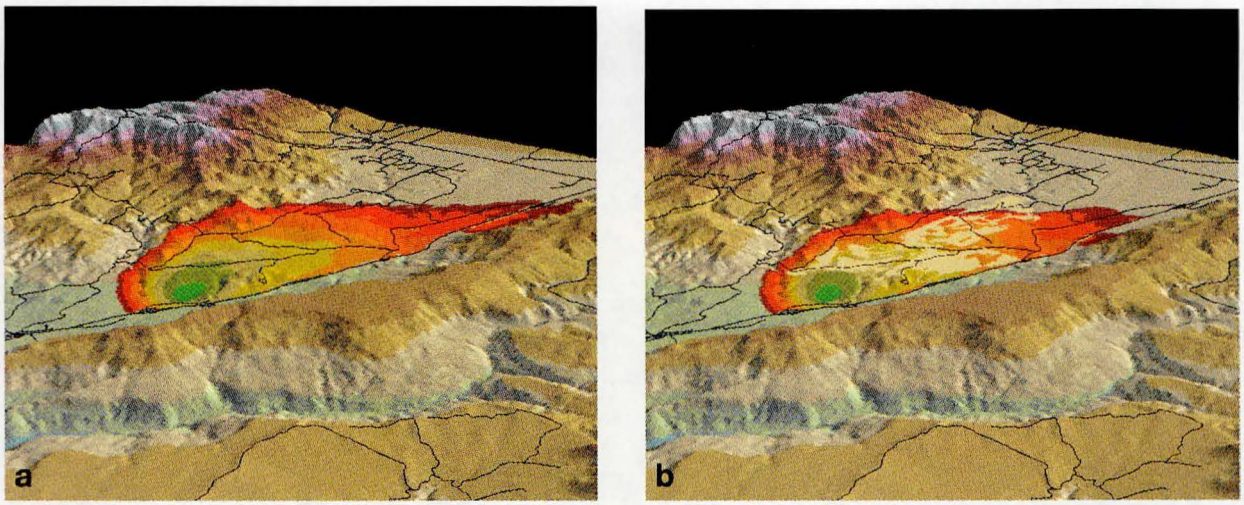


Figure 2. Eight-hour FARSITE simulation for the 85th percentile weather and fuel condition, pre-treatment (a) and post-treatment (b). Each color represents a 1-hour progression of the fire overlaid with roads (black) and the treated landscape (light yellow). Black Ridge is in the foreground and the Pine Valley Mountains in the background (NW). Fuel modifications reduced the size of the fire by approximately 1,500 ac (18%).

Figure 3 displays FlamMap *area maps* of the 85th percentile pre- and post-treatment for flame length, fireline intensity, and crown fire activity. Tabular data for these fire behavior outputs are displayed in Table 2 as well as histograms for flame length and intensity, summarized by the *treatment area* (Figure 4).

Fire Size and Perimeter Growth

A modest reduction in fire size is apparent for each of the percentile weather and fuel conditions. The 85th showed the greatest percent change from the untreated condition (~ 18%), which is likely do to the removal of most of the pinyon-juniper (i.e., fuel model "4s"/"6s"), thus reducing the spotting distance and the number of embers lofted. The 75th percentile simulation shows little change due to the similar surface rates-of-spread in dense, yet sparse pinyon-juniper stands and in recently burned/residual slash areas. As the weather conditions got more severe (95th percentile) and the fire size increased, the effectiveness of the treatments on fire growth diminished.

Although reductions in fire size are evident in all three percentiles, a decline in perimeter growth was only predicted in the 85th percentile. In the case of the 75th percentile, while the treatment reduced surface fuel, the effective windspeed was increased due to the removal of the pinyon-juniper, thus increasing the perimeter and rate-of-spread of the fire—this is also likely the case for the 95th percentile. In the 85th pre-treatment simulation, crown fire runs and spotting in fuel model "4s" and "6s" outpaced the increased effective windspeed.

Table 2. FARSITE and FlamMap fire growth and behavior output for 75th, 85th, and 95th percentile weather and fuel moisture conditions.

75th Percentile	Pre	Post	% Change from Pre
Size (ac)	5,880	5,297	-9.91
Perimeter (mi)	18	18	0.00
Spot Fires*	326	228	-30.06
Surface Flame Length** (ft)	2.97	2.53	-14.81
Fireline Intensity** (BTU/(ft-sec))	84	73	-13.10
Crown Fire*** (ac)	5,756	2,311	-59.85

85th Percentile	Pre	Post	% Change from Pre
Size (ac)	8,588	7,056	-17.84
Perimeter (mi)	28	22	-21.43
Spot Fires*	434	301	-30.65
Surface Flame Length** (ft)	14.93	8.41	-43.67
Fireline Intensity** (BTU/(ft-sec))	2,064	851	-58.77
Crown Fire*** (ac)	10,924	5,761	-47.26

95th Percentile	Pre	Post	% Change from Pre
Size (ac)	24,881	23,202	-6.75
Perimeter (mi)	59	60	1.32
Spot Fires*	1,139	1,054	-7.46
Surface Flame Length** (ft)	17.27	10.44	-39.55
Fireline Intensity** (BTU/(ft-sec))	2,843	1,343	-52.76
Crown Fire*** (ac)	10,924	5,761	-47.26

*Number of spot fires initiated in the treatment area during a 6-hour period.

**Mean flame length and intensity.

***Passive and active crown fire.

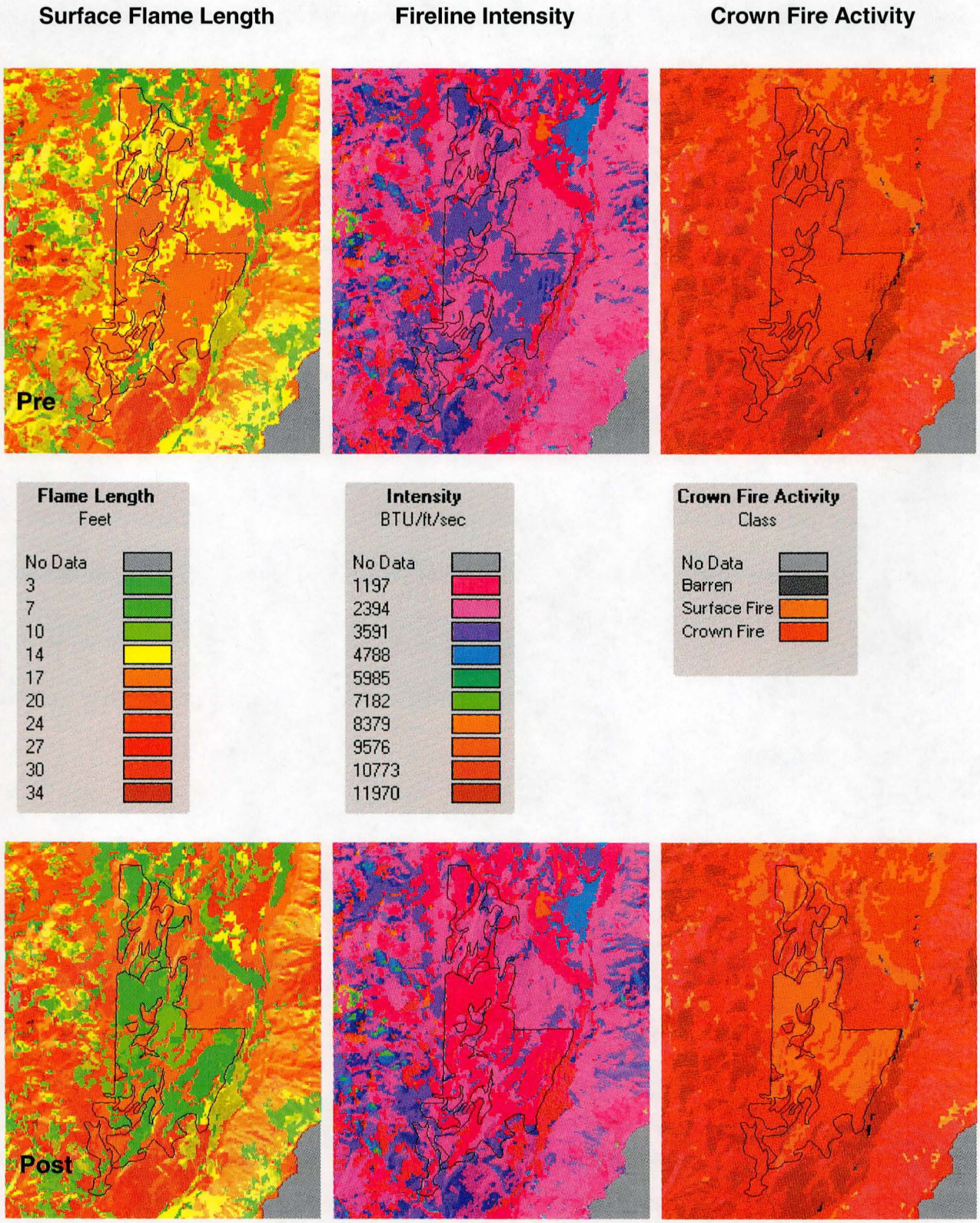
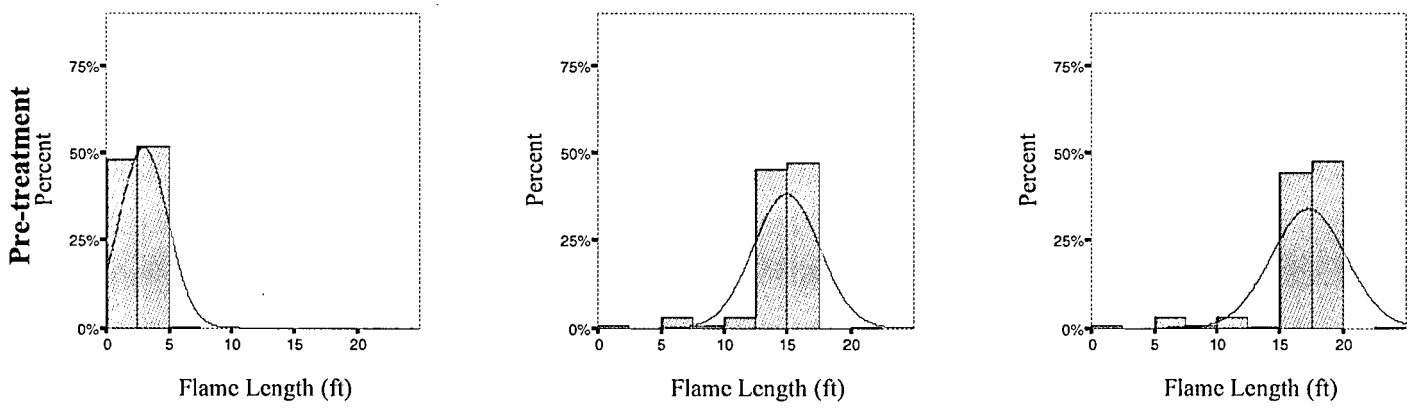


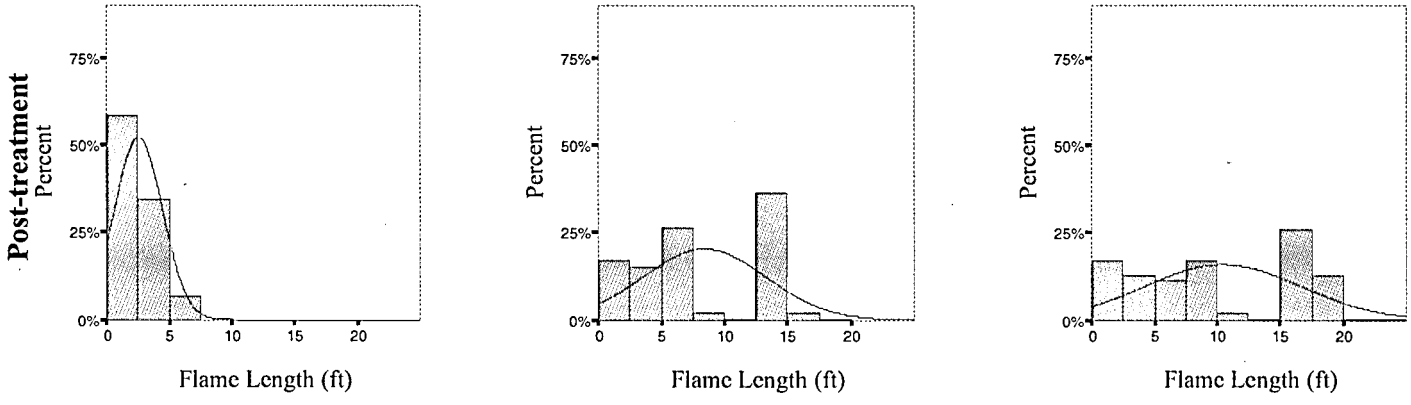
Figure 3. FlamMap output for the 85th percentile condition, pre-treatment (top) and post-treatment (bottom). The project area boundary is overlaid in black and runs north to south—about 4.5 miles.

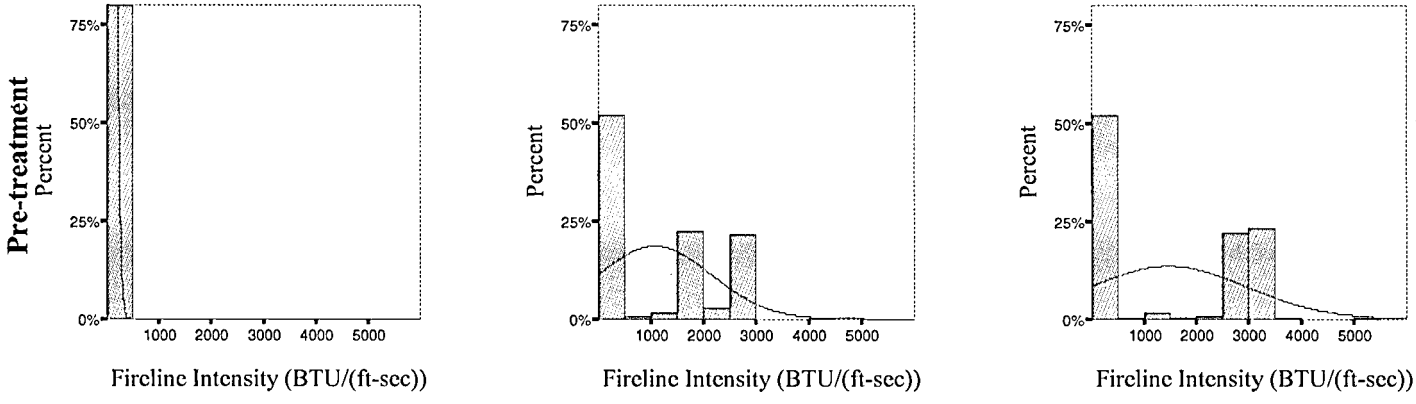
75th Percentile Condition

85th Percentile Condition

95th Percentile Condition







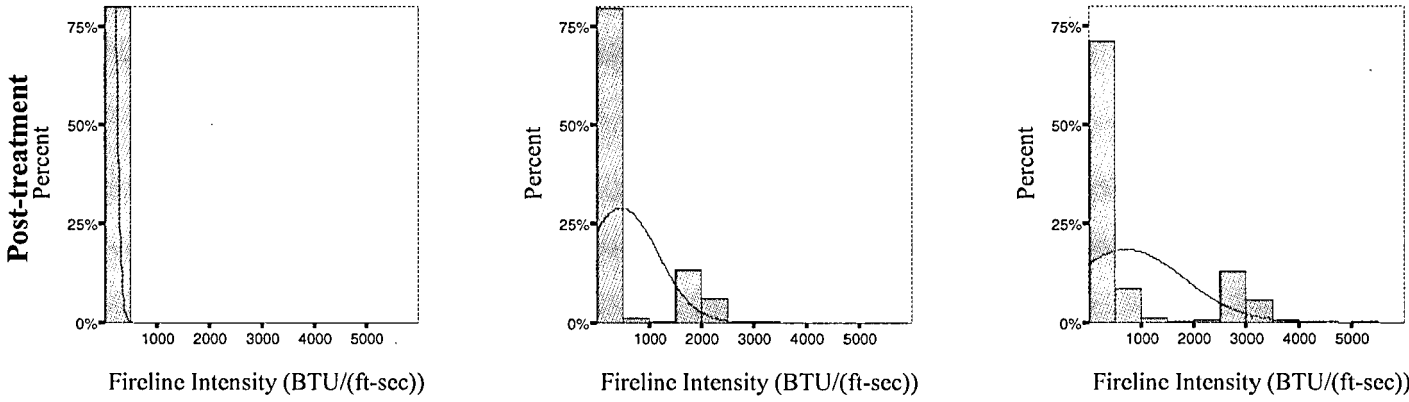


Figure 4. Histograms of FlamMap output for flame length (ft) and fireline intensity (BTU/(ft-sec)), pre- and post-treatment for the 75th, 85th, and 95th percentile weather and fuel condition. The normal curve is displayed.

Spot Fires

A reduction in new ignitions ahead of the main fire front is evident under all three weather conditions. This is due largely to the removal of the pinyon-juniper. It is worthy to remember that spotting in FARSITE is stochastic and the numbers of embers lofted and burning when they reach the ground are dependent on the spotting model (Albini 1979) and largely influenced by the ignition frequency and canopy characteristics. Thus, this information is imprecise and more emphasis should be given to the percent change, rather than the actual number of fires.

Intensity and Flame Length

Changes in both intensity and flame length for all three percentile classes were realized in the project area and are recorded in Table 2 and plotted in Figure 4. The histograms more adequately display the changes in fire behavior between percentiles and treatment conditions than the single mean value for flame length and fireline intensity (Table 2).

Crown Fire

Although FlamMap differentiates between passive and active crown fire, Table 2 summarizes both types of crown fire as one. This was done due to the under prediction of active crown fire in FlamMap and FARSITE as compared to observed conditions (Cruz and others 2003; Fulé and others 2001; Scott and Reinhardt 2001). For example, in the 85th percentile condition, all crown fire was termed "passive;" in the 95th, only a slight amount (190 acres) had transitioned to an active crown fire, thus the identical values between pre- and post-treatment landscapes.

Discussion

Modeling Assumptions and Limitations

There are several assumptions and limitations to the methodology presented in this paper. FARSITE and FlamMap, as well as the models utilized by these modeling systems (e.g., surface fire spread, crown fire spread), operate under a broad range of assumptions and have specific limitations. Spatial data has resolution and accuracy limits inherit to mapping of heterogeneous surface and canopy fuels and terrain. Vegetation cross-walked to fuel model and fuel model assignments of treated landscapes are occasionally problematic and model output is largely a reflection of these "conversions." Moreover, RAWS information can be incorrect, unavailable, or influenced by local factors not known to the end-user. It is important that users understand model constraints, and more importantly utilize models and output within accepted bounds.

FARSITE or FlamMap?

FARSITE was used to simulate fire spread and spotting potential, although several other outputs are available, including fireline intensity, flame length, and crown fire activity. Instead, FlamMap was used to calculate these fire behavior outputs, for a number of reasons, including: (1) FlamMap calculations are near instantaneous where as FARSITE simulations can oftentimes take several hours; (2) FlamMap's primary design is to distinguish hazardous fuel and topographic conditions, making pre- and post-treatment comparisons and contrasts across landscapes much easier and more suitable than in FARSITE; (3) Although historical fire occurrence was used in this analysis, there is no guarantee future fires will occur in these areas. While a pattern is often evident, demographics, human activities, and climatic conditions can change. Therefore, selecting a specific fire start is often subjective—particularly with little or no ignition data—yet tremendously significant to the outcome of the simulation(s), thus not requiring this input (FlamMap) is advantageous; (4) Other parameters such as determining the distance to the treated area, developing the wind file, specifying the simulation duration, and setting fire behavior parameters, are largely at the discretion of the modeler and difficult to fully substantiate, whereas fewer parameters are required in FlamMap; (5) Many fires that often impact an area of concern, such as a community like Harmony Heights, start considerable distances away from the area they threat, so assessing an area with a single, localized run is limiting.

Modeling Discussion

A great deal of information can be obtained by modeling the effect of fuel treatments on fire growth and behavior and analyzing model outputs. Ideally, modeling will be done *before* the actual treatment is implemented so model findings can be incorporated to modify the treatment pattern, size, methods, etc. However, post analysis of fuel breaks, as in this case, can substantiate management decisions, yield useful findings for future projects, and identify weaknesses in treatment design and application.

At first glance, fuel modifications seem to have had little effect on the fire (Figure 2). In respect to fire growth, this is the case under certain weather conditions. Indeed, some modifications may have even *increased* the rate of spread, by exposing previously

sheltered fuels. However, changes in other fire behavior characteristics are considerable, thus accomplishing the objectives of the treatment (Table 2).

An area where modeling suggests additional landscape treatment may be beneficial is along the southeast corner of I-15. The large, southeastern most treatment polygon stands alone if a fire approaches from the south. This is due to private ownership directly to the north. Previous modeling indicates the most effective treatment design tends to be those that have fuel modifications in succession and distributed across the landscape (Finney 2001). Moreover, the *sooner* a fire encounters a fragmented fuel complex the greater will be the effectiveness of that treatment on disrupting or locally blocking fire growth. Therefore, a second phase of this project might consider additional polygons to the south, like those in succession to the west. By so doing, a fire spreading to the north would encounter several fuel breaks before reaching the public land to the north, thus reducing the forward fire spread rate and assisting firefighting efforts.

Finally, modeling allows for hypotheses testing. For example, "what is the 'breaking point' of the Ash Creek treatment when the weather and fuel conditions are such that treatment effectiveness is minimized in respect to fire growth?" Through multiple simulations with varying weather scenarios, this question can be theorized at the 88th to 92nd percentile.

Conclusion

Managers have a growing need to assess the effectiveness of landscape fuel treatments, however this need has outpaced the development of spatial models to accomplish the task. FARSITE, although not originally intended to do so, has been used to assess treatment effectiveness on fire growth and behavior (Stephens 1998; Van Wagtendonk 1996). The methodology presented in this paper uses FARSITE, but also incorporates FlamMap, Fire Family Plus, and previous ignition history to assess fuel treatment effectiveness. Although the approach has limitations, model outputs yield useful information for planning, assessing, and prioritizing fuel treatments. In the future, planned enhancements to Flammap will enable users to evaluate landscape alterations on fire spread utilizing minimum travel time methods (Finney 2002) and eventually aid in optimizing treatment design to mitigate fire behavior and spread.

Acknowledgments

This analysis was supported by the Joint Fire Sciences, Southern Utah Demonstration Project, the Cedar City Field Office of the BLM, and the USDA Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory. The author expresses his thanks to Mark Finney, Kevin Ryan, Donald Long, Mo Mislivets, Miguel Cruz, Steve Small, and Paul Briggs for their support, review, and comments.

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GREENVILLE BENCH CASE STUDY ANALYSIS

Rick D. Stratton, Donald Long, and Maureen Mislivets

Abstract

This paper presents the use of two models to aid managers in identifying and prioritizing areas for landscape fuel treatments. Treatment areas were selected by fire managers from the Bureau of Land Management based on the threat of fire to communities and the need for watershed, range, and wildlife improvement. FlamMap was used to calculate fireline intensity and crown fire activity. The Minimum Travel Time technique was used to reveal the most influential travel paths of fire spread. Output from both models reveal potential areas of concern and aid managers in the prioritization of these areas for landscape fuel treatments.

Introduction

Fuel modifications are receiving renewed interest as protection strategies, particularly in wildland-urban areas (Agee and others 2000). This is a result of costly fire seasons like 2000 and 2002, new national directives with increased funding (USDA Forest Service and USDI 2000), a recognition of a change in fuel composition, structure, and loading, and fire manager's desire, yet limited ability, to control large fires. The primary purpose of a fuel treatment is to change the behavior of a fire entering a fuel-altered zone, thus lessening the impact of that fire to an area of concern. This is best achieved by fragmenting the fuel complex and repeatedly disrupting or locally blocking fire growth, thus increasing the likelihood that suppression will be effective or weather conditions will change (Finney 2000).

Recent research suggests that landscape-scale fuel modifications, such as prescribed fire, are the most effective way to modify the behavior and growth of large fires (Finney 2001), but managers have lacked the tools and information necessary to identify and prioritize treatment areas at a landscape level. This paper presents the use of two models to aid in identifying and prioritizing areas for landscape fuel treatments: FlamMap (Finney, in preparation) and the Minimum Travel Time (MTT) (Finney 2002).

Analysis Area

Greenville Bench is located approximately 10 miles southwest of Beaver, Utah and is south and east of the communities of Greenville, Adamsville, and Minersville (Figure 1). The project area (approx. 40,000 acres; 5,600 to 7,600 ft) is on Bureau of Land Management (BLM) administered land and bounded by private ownership to the north (Greenville Bench Road and State Road 21), Interstate 15 (I-15) to the east, Rocky Ford Hollow to the west (BLM), and a ridgeline to the south (Bald Hills; BLM). Several sections of State administered land is distributed throughout the area. The Greenville Bench and associated uplands are southeast of Minersville Reservoir, constituting the southwestern quarter of the Beaver River Watershed.

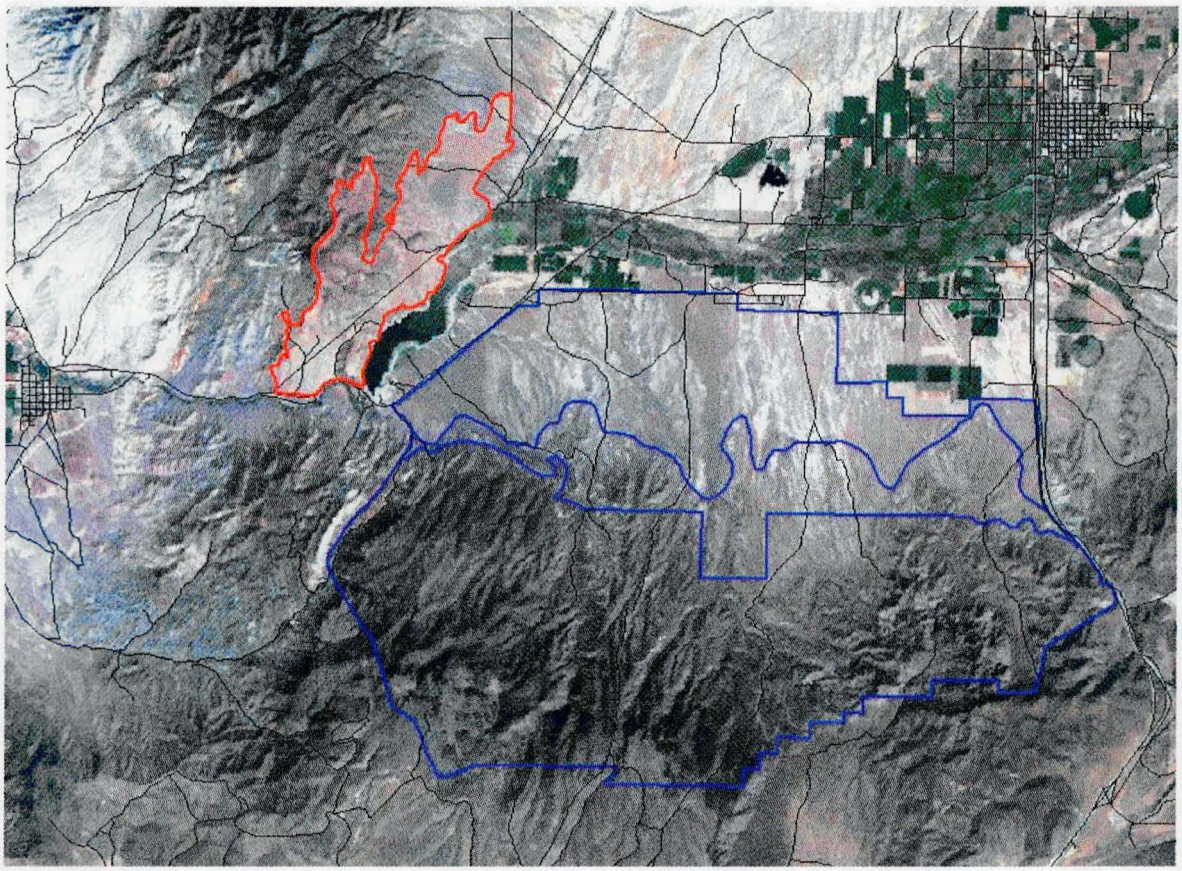

Figure 1. Vicinity map of the Greenville Bench project area. The blue polygon is the project boundary divided primarily by sagebrush to the north (up) and pinyon-juniper to the south. The Minersville Fire of 1998 (4,060 acres) is in red and roads are in black, with Beaver, UT in the northeast corner and Minersville to the west. The base map is a LANDSAT 5 Thematic Mapper image, bands 3, 2, and 1.

Located on an alluvial fan, the relatively flat bench transitions to steep, north facing slopes. The dominant vegetation communities on the lower bench are sage brush (*Artemisia tridentata*) (1-3 ft), interspersed in a lesser degree with crested wheatgrass (*Agropyron cristatum*), bluebunch wheatgrass (*Elymus spicatus*), junegrass (*Koeleria macrantha*) (1-2 ft), transitioning on the upper slopes to dense stands of Utah juniper (*Juniperus osteosperma*) and pinyon pine (*Pinus edulis*) (10-35 ft), with some oak (*Quercus turbinella*; *Quercus gambelii*) in the draws (4-15 ft).

Summer cold fronts contribute to strong winds that are channeled through the State Road 21 corridor and the surrounding area and onto the lower Greenville Bench. The effect of these winds on fire growth is evidenced by the Minersville Fire of 1998 (4,060 acres) (Figure 1). The area has a history of fires attributed to recreational use, I-15 through traffic, and lightning on the Mineral Mountains to the northwest (9,600 ft) and the Black Mountains to the southwest (8,000 ft).

Due to decades of fire suppression and previous grazing practices, pinyon-juniper woodlands have increased in range and density and currently occupy areas previously

dominated by sagebrush and perennial grasses. Furthermore, remnant shrublands now contain mostly homogenous stands of mature sagebrush, with declining native perennial forbs and grasses. Higher elevation areas where dense pinyon-juniper exists have little understory, the presence of which is important to wildlife and ecosystem stability. The sagebrush corridors that once connected the Bald Hills with Greenville Bench, and facilitated the movement and dispersal of sagebrush obligate species (e.g., sage grouse), have been eliminated due to the pinyon-juniper encroachment (USDI 2003).

> The following actions have been identified by resource and fire management professionals as necessary on the Greenville Bench area: 1) establishing fuel breaks along selected roads, property lines, and topographic features on the lower sagebrush bench creating a situation where wildfires can be better managed by reducing the rate of spread and giving fire fighters additional response time to suppress fires; 2) decreasing the hazardous fuel loads on the mid and upper slopes in the pinyon-juniper woodland, thereby protecting against the threat of catastrophic wildfires leaving the woodlands and impacting neighboring private lands and I-15; 3) re-establishing sagebrush corridors between the Bald Hills and the Greenville Bench allowing for better dispersal and movement of wildlife species; 4) decreasing the amount of pinyon-juniper encroachment into areas historically dominated by big sagebrush; 5) increasing plant diversity within the treatment areas by establishing a mix of native and non-native shrubs, forbs, and grasses that would also facilitate a decrease in surface soil erosion as a result of precipitation and wind. (USDI 2003)

Methods

Specific information about the project area, such as objectives of the proposed treatment (e.g., wildfire control, wildlife enhancement), type of treatment (e.g., prescribed fire), and supporting Geographic Information System (GIS) data were obtained from the BLM. A 32-year fire ignition layer for the BLM was used to derive a fire density grid, using ArcView/Spatial Analyst (ESRI 2000) (Figure 2).

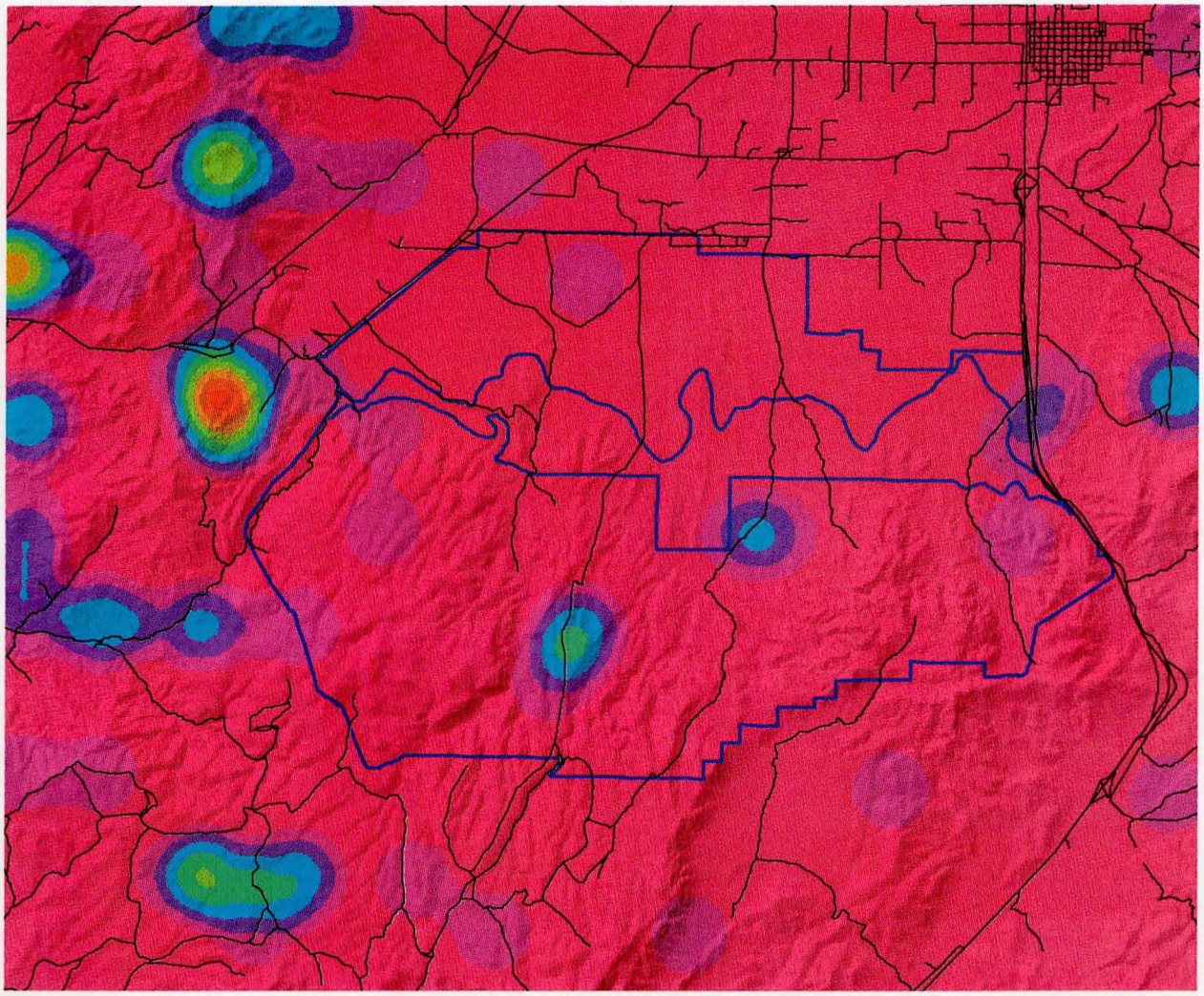

Figure 2. Thirty-two year (1970-2001) fire density grid of the Greenville Bench area. The blue polygon is the project area divided primarily by sagebrush to the north (up) and pinyon-juniper to the south; roads are in black. Fire density is recorded by number of fires per square mile and range from 0 fires (lavender), 1 fire (purple), 2 fires (green), 3 fires (blue), and 4 fires (red).

Locations of the nearest Remote Automated Weather Stations (RAWS) were identified and reporting history and site characteristics were analyzed to determine the most adequate station for the project area. Horse Hollow, approx. 20 miles north of Beaver, UT, with a 13-yr history, was selected and its information downloaded from NIFMID/KCFAST (USDA Forest Service 1993; USDA Forest Service 1996) fire occurrence information retrieval site and imported into Fire Family Plus (Bradshaw and McCormick 2000).

Vegetation and Fuel Models

Spatial vegetation data for the project area was extracted from a larger 15 million acre study area (Long and others, in preparation). A supervised classification of LANDSAT

Thematic Mapper data—path 33 and rows 37 and 38—was used with ERDAS IMAGINE software (ERDAS 1999), incorporating polygons created by the IPW image processing program (Frew 1990). A maximum likelihood algorithm in ERDAS was used to classify the imagery based on a statistical representation of spectral signatures for each vegetation class created from field sampling. Ancillary layers, including land use and land cover, were used in combination with the classified imagery to assign polygons to one of 65 final vegetation classes.

The vegetation classes were cross-walked to 44 fuel models (including barren and water), 35 of which were "customized" models (i.e., the standardized model parameters (Anderson 1982) were altered to reflect a condition not adequately represented by the fire behavior models) and two, were custom models (i.e., 14: sparse grass-forb; 35: sparse shrub). Canopy cover, stand height, crown-base height, and crown bulk density were developed based on field data, anecdotal observations, and previously published work. Moderate and severe custom fuel files (*.FMD) were built to reflect the differences in fire behavior between moderate and high/severe conditions.

Terrain, fuel model, and canopy information was used to construct two modeling landscapes: pre-treatment and post-treatment. Lower bench sage-dominated areas were assigned either a fire behavior model (2, 6) or a customized model (e.g., 2-, 5+, 6-, etc; where the "-" or "+" represents a 20% change in the loading and depth). Stands of pinyon-juniper and oak were assigned a standardized fuel model (4, 6) or a customized model (4-, 6-, 6--), *each with varying canopy characteristics*.

Fire Family Plus

Fire Family Plus is a fire climatology and occurrence program that combines and replaces the PCFIRDAT (Cohen and others 1994; Main and others 1990), PCSEASON (Cohen and others 1994; Main and others 1990), FIRES (Andrews and Bradshaw 1997), and CLIMATOLOGY (Bradshaw and Fischer 1984) programs into a single package with a graphical user interface. It allows the user to summarize and analyzing weather observations and compute fire danger indexes based on the National Fire Danger Rating System (NFDRS) (Bradshaw and others 1983; Burgan 1988).

Fuel moistures (i.e., 1-, 10-, 100-hr, live herbaceous, live woody) were obtained from a Fire Family *Percentile Weather Report*. Calculated fuel moistures were compared with local field sampling to validate and adjust the values. Wind speed, temperature, and relative humidity were obtained from a *Seasonal Severity Report*; wind direction was obtained from a *Wind Speed vs. Direction Report*. Wind speeds were modified to account for persistent gusts (NOAA 2003).

All weather and fuel moisture information was recorded at the 90th percentile (Table 1). In other words, weather occurring during the reporting period (June 1-September 30) 10% of the time is represented by the 90th percentile. This percentile was used because suppression forces are virtually ineffective when weather and wind conditions are between the 88th and 95th percentile. All climatological and fuel variables were then used to develop the required weather and wind files/inputs for FlamMap and the MTT.

Table 1. Weather and fuel moisture information for the 90th percentile from the Horse Hollow RAWS and reported by Fire Family Plus and modified as noted (*/**).

	90th
1-hr (%)	3
10-hr (%)	5
100-hr (%)	6
Live Herbacious (%)*	60
Live Woody (%)*	90
Foliar Moisture Content (%)	85
20-ft Windspeed (mph)**	20
Wind Direction (°)	235

*Adjusted from the *Seasonal Severity Report* based on local field sampling.

**Adjusted from the *Seasonal Severity Report* to account for wind gusts (NOAA 2003).

FlamMap

FlamMap is a spatial fire behavior mapping and analysis program, which requires a FARSITE (Finney 1998) landscape file (*.LCP), as well as terrain, fuel, and weather data. However, unlike FARSITE, FlamMap assumes that *every* pixel on the raster landscape burns and makes fire behavior calculations (e.g., fireline intensity, flame length) for each location (i.e., cell), *independent* of one another. That is, there is no predictor of fire movement across the landscape and weather and wind information can be held constant. By so doing, FlamMap output lends itself well to landscape comparisons (e.g., pre- and post-treatment effectiveness) and for identifying hazardous fuel and topographic combinations, thus aiding in prioritization and assessments.

Minimum Travel Time

Fire travel times across a two-dimensional landscape were calculated by overlaying a rectangular lattice on a spatial data set consisting of terrain, fuels, fuel moisture, and wind. The MTT was then obtained by searching for the fastest path of travel along straight-line transects connecting the nodes (cell corners) of the lattice (Finney 2002). These MTT paths were then interpolated to reveal the position of the fire perimeter at an instant in time. Based on output from the MTT algorithm, the amount of land area burned after the fire exists each node is calculated and nodes exhibiting the greatest "fire influence" are revealed.

Fire perimeters and behavioral characteristics (e.g., spread rate, fireline intensity) from the MTT closely resemble products from perimeter expansion models, such as FARSITE, but because MTT methods are more readily parallelized, processing time is significantly decreased (Finney 2002).

Model Checking and Execution

To produce fire growth and behavior output consistent with observations, model checking, modifications, and comparisons were done using fire models, such as FARSITE and Behave Plus (Andrews and Bevins, in preparation), case studies, other published work, and anecdotal observations. Ninetieth percentile weather and fuel conditions were imputed into FlamMap and the MTT. A wind direction of 235° was used in Flammap and the MTT based primarily on the historical weather analysis, but confirmed by spread directions of previous large fires. A line ignition along the western extent initiated fire spread into the study area.

Results

Figure 3 and 4 displays FlamMap output for the for 90th percentile weather and fuel condition. Fireline intensity (Figure 3) is expressed in BTU/(ft·sec) and concentrated to the lower values. Crown fire activity (Figure 4) is expressed categorically as either areas of no fire (i.e., barren, water), surface fire, passive crown fire, or active crown fire.

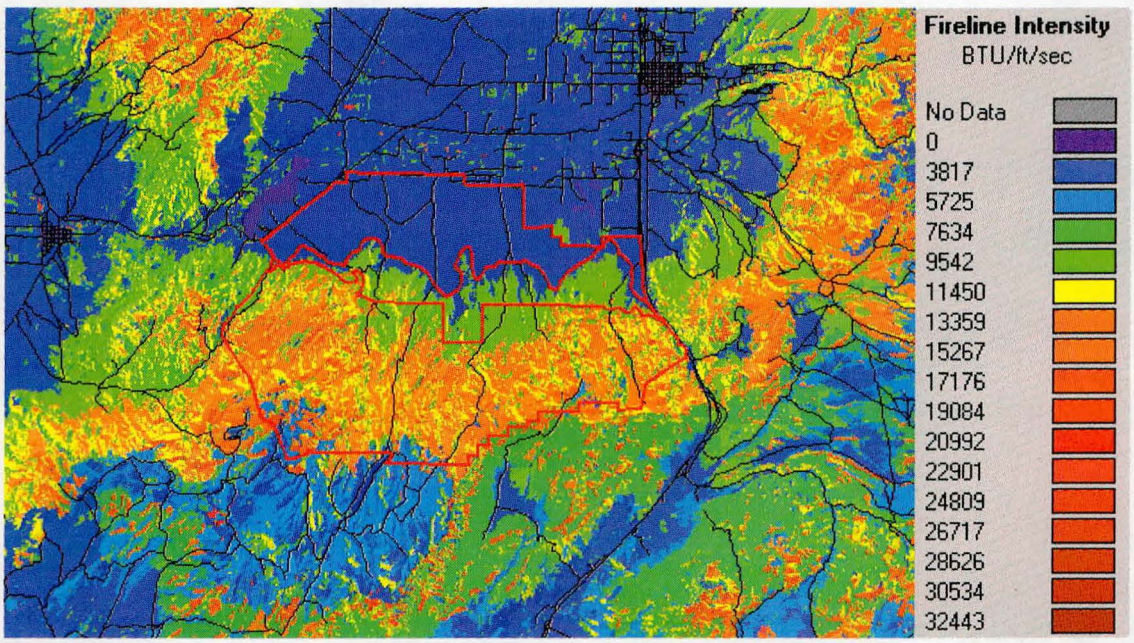

Figure 3. FlamMap fireline intensity map for the 90th percentile weather condition. The red polygon is the project area divided primarily by sagebrush to the north (up) and pinyon-juniper to the south; roads are in black, with Beaver, UT in the northeast corner.

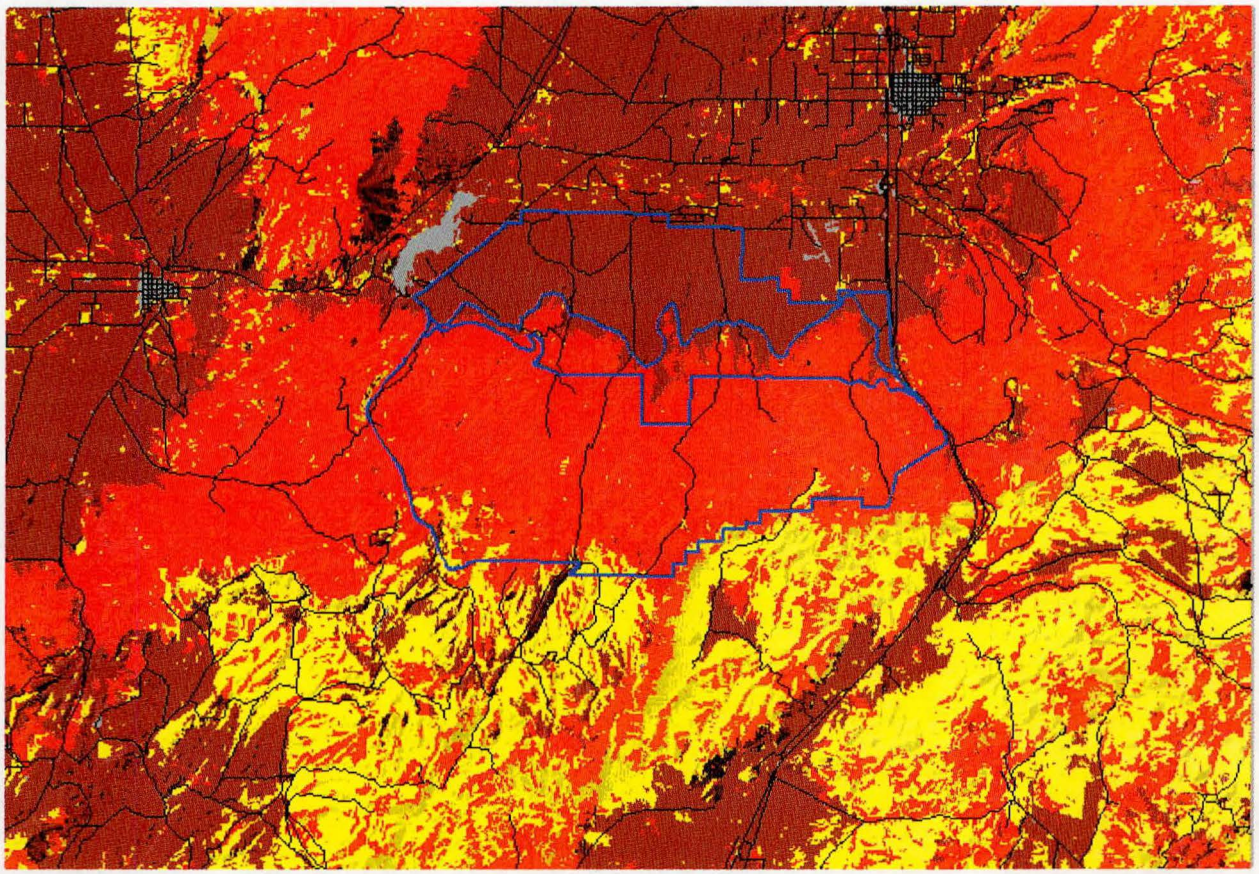

Figure 4. Crown fire activity map for the 90th percentile weather condition. The blue polygon is the project area divided primarily by sagebrush to the north (up) and pinyon-juniper to the south; roads are in black, with Beaver, UT in the northeast corner. Crown fire activity is recorded by no fire areas (gray), surface fire (dark red), passive crown fire (yellow), and active crown fire (red).

Figure 5 displays fire influence pathways derived from the MTT technique. These paths indicate the corridors where the greatest amount of land area was burned. The various colors are a measure of land area burned, where the red and orange pathways went on to burn the most acreage, followed by yellow, then green.

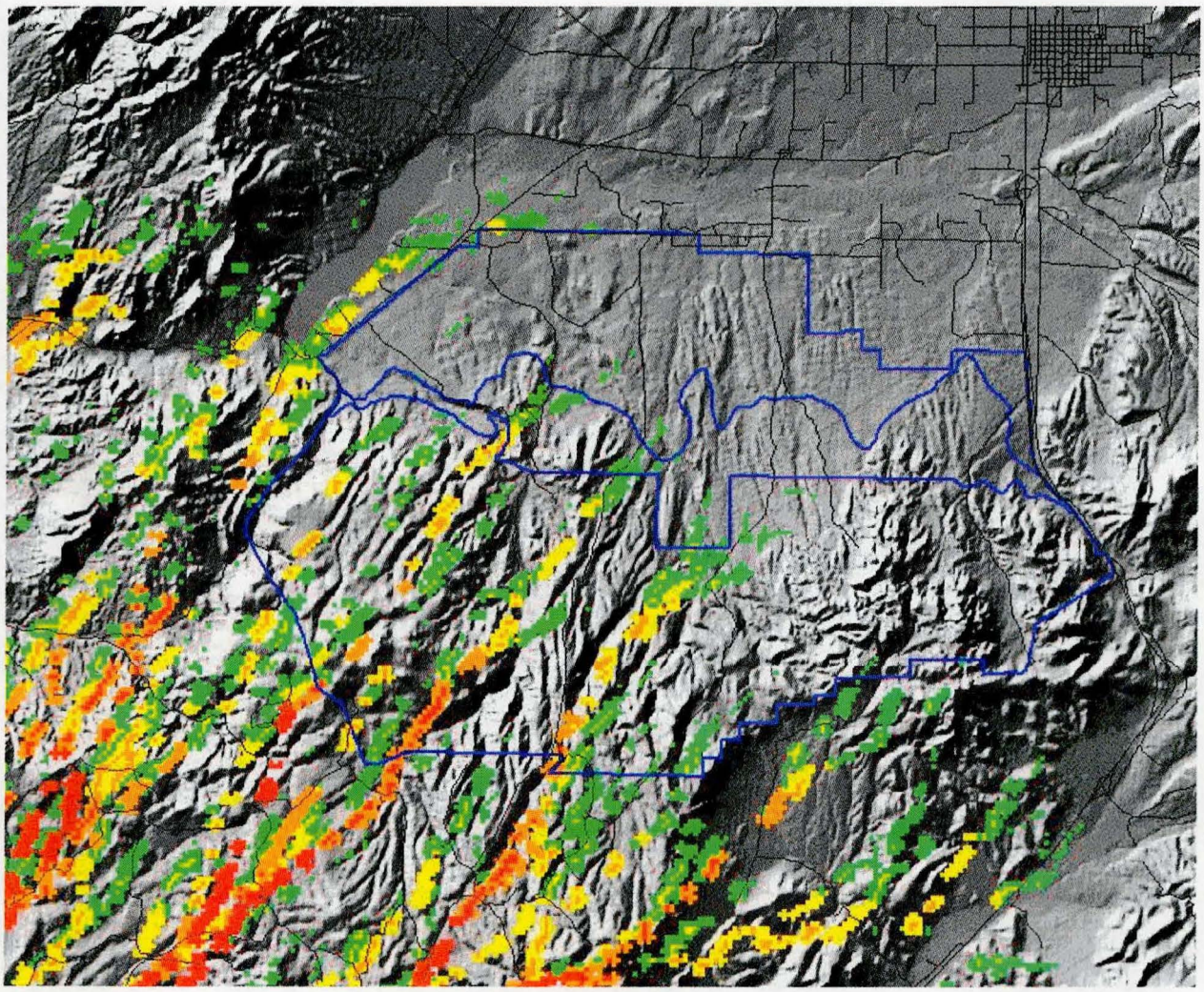

Figure 6. Pathways of "greatest influence" derived from the MTT technique for the 90th percentile weather condition. The various colors are a measure of land area burned, where the red and orange pathways went on to burn the most acreage, followed by yellow, then green. The Greenville Bench project area is the blue polygon with Beaver, UT in the northeast corner. Roads are colored black, and overlaid with a 30-meter shaded relief map.

Discussion

Modeling Assumptions and Limitations

There are several assumptions and limitations to the methodology presented in this paper. FlamMap and the MTT method, as well as the models utilized by these modeling systems (e.g., surface fire spread), operate under a broad range of assumptions and have specific limitations. Spatial data has resolution and accuracy limits inherit to mapping of heterogeneous surface and canopy fuels and terrain. Vegetation cross-walked to fuel model and fuel model assignments of treated landscapes are occasionally problematic and model output is largely a reflection of these "conversions." Moreover, the MTT algorithm is still under development and this

paper constitutes it first applied use; thus, it is important that users understand model constraints, and more importantly utilize models and output within accepted bounds.

Model Output and Discussion

Products form FlamMap and the MTT technique can assist managers in identifying areas of concern and aid in the prioritization of these locations for fuel treatment. Although these output grids are in themselves limiting, collectively they provide useful information for assessing wildland fire danger.

Fireline Intensity

The fireline intensity grid can be used to identify areas of potential concern. Higher intensity areas generally are more resistant to control, exhibit high flame lengths, spotting, and mortality.

Crown Fire Activity

The crown fire map can be used to reveal areas prone to active crown fire. Such areas are generally very difficult to control, prolific spotters, and exhibit high rates of spread. Thus, targeting areas such as these for landscape fuel modifications could prove beneficial.

MTT

Unlike fireline intensity and crown fire activity (i.e., fire behavior predictors of the physical setting), the MTT algorithm identifies potential areas of concern based on fire growth. There are two principal uses of this information: mitigating large fire growth and behavior and the protection of human and ecological values. To aid in reducing large fire growth, pathways of primary influence (i.e., the red and orange, or those areas that went on to burn the most acreage) can be targeted for landscape fuel modifications. By applying these treatments heuristically—to multiple areas, in varying sizes and shapes—modifications in large fire growth and behavior will be realized.

To protect areas of concern such as wildland-urban areas, threatened and endangered species habitat, cultural resources, etc., secondary corridors should be overlaid with protection areas to identify areas of hazard (i.e., a physical situation with a potential for loss (Allen 1992). Finer-scale treatments can then be designed to mitigate the risk to these protection areas.

Conclusion

Managers have a growing need to identify and prioritize landscapes for fuel treatment, however this need has outpaced the development of spatial models to accomplish the task. FlamMap provides managers with estimations for fireline intensity and crown fire activity. Use of the MTT identifies likely spread routes and high influence pathways. These data are beneficial in identifying and prioritizing areas for landscape fuel treatments. However, to sufficiently alter fire growth and behavior an interactive approach, where managers would run the MTT, input fuel treatments, and rerun the algorithm—possible several times—would reveal an improved treatment design. It is anticipated that future versions of FlamMap will incorporate the MTT technique and an optimization model to accomplish this task.

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